United States
Department of
Agriculture

Forest Service

Rocky Mountain
Forest and Range
Experiment Station

Fort Collins
Colorado 80526

General Technical
Report RM-243

Proceedings
Northeastern and
Intermountain Fores
and Conservatio
Nursery Association

August 2-5, 199
St. Louis, Missou

Abstract – Landis, Thomas D., tech. coord. 1994. Proceedings, Northeastern and Intermountain Forest and Conservation Nursery Associations; 1993 August 2-5; St. Louis, MO. General Technical Report RM-243. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 158 pp.

This proceedings is a compilation of 25 articles on various aspects of nursery management in northern and western North America. In addition to general nursery technical reports, this publication contains papers relating to three special focus topics: Soil Management, Organic Matter Management, and Integrated Pest Management and Biocontrol.

Keywords: bareroot seedlings, container seedlings, nursery practices, reforestation.

Note: As part of the planning for this symposium, we decided to process and deliver these proceedings to the potential user as quickly as possible. Thus, the manuscripts did not receive conventional Forest Service editorial processing, and consequently, you may find some typographical errors. We feel quick publication of the proceedings is an essential part of the symposium concept and far outweighs these relatively minor distractions. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations or the USDA Forest Service. Trade names are used for the information and convenience of the reader, and do not imply endorsement or preferential treatment by the sponsoring organizations or the USDA Forest Service.

USDA Forest Service
General Technical Report RM-243

March 1994

Proceedings: Northeastern and Intermountain Forest and Conservation Nursery Associations

Thomas D. Landis, Technical Coordinator

Funding for this publication was provided as a technology transfer service by State and Private Forestry, USDA Forest Service

ACKNOWLEDGMENTS

The professional success of this meeting was due in no small part to the willingness of many people to come and share their knowledge and experience. Many of the members of the nursery associations are government employees and as such are financially reimbursed for their time and expenses. This is not the case for private nurseries and consultants, however, and so we would like to acknowledge their unselfish contributions.

The following companies contributed both technically and financially to the success of this meeting, and we would like to acknowledge their support:

Baertschi of America, Inc.
P.O. Box 5139
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Hendrix and Dail, Inc.
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Truax Company, Inc.
3609 Vera Cruz Ave.
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Whitfield Forestry Equipment
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Nitrate Non-point Pollution Potential in Midwestern Bareroot Nurseries[1]

Richard C. Schultz, Janette R. Thompson, Paul Ovrom, Charles A. Rodrigues [2]

Abstract– Non-point source (NPS) pollution is a major contributor to poor surface and groundwater quality in the United States. Agriculture is the major contributor to NPS pollution, with NO_3-N, certain pesticides, and sediment being the major pollutants. Bareroot nurseries manage the land more intensively than most cultivated agricultural systems. High levels of nitrogen fertilizer, numerous chemical pesticides, and surface erosion from fallow beds and paths can contribute to surface and groundwater pollution. The Hardwood Nursery Cooperative conducted a study during the 1992 growing season to determine the fate of nitrogen fertilizers applied to nursery beds. Results suggest that the potential for NPS pollution from nitrogen fertilizer applications exists under present fertilizer regimes. NO_3-N concentrations as high as 35 mg/L (ppm) were consistently found at 15 cm (6 in) depths and concentrations between 15 and 20 mg/L (ppm) were found at 1 m (3 ft) depths. The results of this study indicate that bareroot nurseries may be a source of NPS pollution for NO_3-N. Nursery managers should determine the effect of fertilizer applications on NPS pollution and modify fertilizer application regimes accordingly.

INTRODUCTION

As the world population continues to increase greater demands are placed on natural resources that are on a smaller and smaller land area. To increase the productivity of these natural resources modern management techniques depend heavily on chemical inputs. These chemical inputs create a potential for pollution of surface and groundwater systems.

The bareroot nursery industry, in an attempt to produce high quality seedlings, has depended on high inputs of inorganic and organic fertilizers which may be resulting in local pollution of the water system. Although this source of non-point source (NPS) pollution does not cover a major land area, fertilizer rates per unit of area often exceed those used in agriculture and thus create a potentially hazardous situation. In an attempt to understand the fate of nitrogen fertilizer, the most frequently added nutrient in nurseries and agriculture, the Hardwood Cooperative, consisting of the state forest nurseries of Illinois, Iowa (two nurseries), Minnesota, Missouri, and Ohio, conducted a study, during the 1992 field season, to determine what happens to applied nitrogen fertilizer. The purpose of this paper is to report the preliminary results of that study.

However, before describing those results a brief review of the concepts of pollution, water quality, transport of nitrogen through the ecosystem, and the possible fate of nitrogen in bareroot nurseries will be presented. A more in-depth review is presented by Landis et al. (1992). The discussion of the study will identify levels of NO_3-N nitrogen in the top meter (3 ft) of nursery bed soil, the quantity of nitrogen uptake by seedlings, the resulting growth of the seedlings, and the implications of these results for NPS pollution and seedling production.

A major looming global crisis is the shortage of high quality water needed to sustain human life. Although regionally the supply of water may be a problem, globally the major concern is the quality of available water. Both surface and groundwater quality are being impacted by human activities. Worsening groundwater quality is a particular problem because of the slow movement of groundwater. Once it is contaminated it tends to stay that way because dilution is very slow (Biernbaum and Fonteno, 1989). The increasing global population and the mismanagement of the present water supplies threatens one of the most limiting resources on the planet.

Water quality can be defined as it's physical, chemical, and biological characteristics with re-

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

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gards to a particular use. The physical characteristics of water include such items as: a) suspended sediment which can modify the turbidity or clarity of the water and which can carry adsorbed chemicals; b) water temperature which effects both chemical and biological activity in the water; c) dissolved oxygen which can determine the ability of water to maintain certain species of animal life; and d) pH and alkalinity which indirectly indicate the nutrient carrying capacity of water and its chemical activity. Dissolved chemical constituents of water come from atmospheric inputs such as dryfall and wet fall, geological weathering of rocks and soil constituents, biological inputs such as nitrogen fixing microbes, and human derived chemicals from land management activities. Major chemicals that readily move through the system include nutrients and pesticides. The biological characteristics of water are concerned with beneficial and harmful micro- and meso-organisms.

Pollution is the process of degrading water in some way resulting in an undesirable change for a particular use. The key to the definitions of water quality and pollution is the concept of particular use. The quality of water used simply for crop irrigation can be substantially less than water used for human consumption. The problem is that water moves continuously through soils, plants, streams, lakes, and oceans creating the hydrologic cycle. The continuously connected reservoirs of that cycle are tapped in many places for drinking water which must be of the highest possible quality. Thus the U.S. Environmental Protection Agency (EPA) has established drinking water standards called maximum contaminant levels (MCL's) for various chemicals that apply to all water in the hydrologic cycle that is directly tapped for human use.

Because water applied to bareroot nursery beds moves through the unsaturated soil to the groundwater table and then to the nearest stream or lake it must meet drinking water standards or be considered a source of potential pollution. For decades fertilizer use in agriculture or nurseries was low enough not to overwhelm the dilution effect of water bodies. However, under present management scenarios this is no longer true.

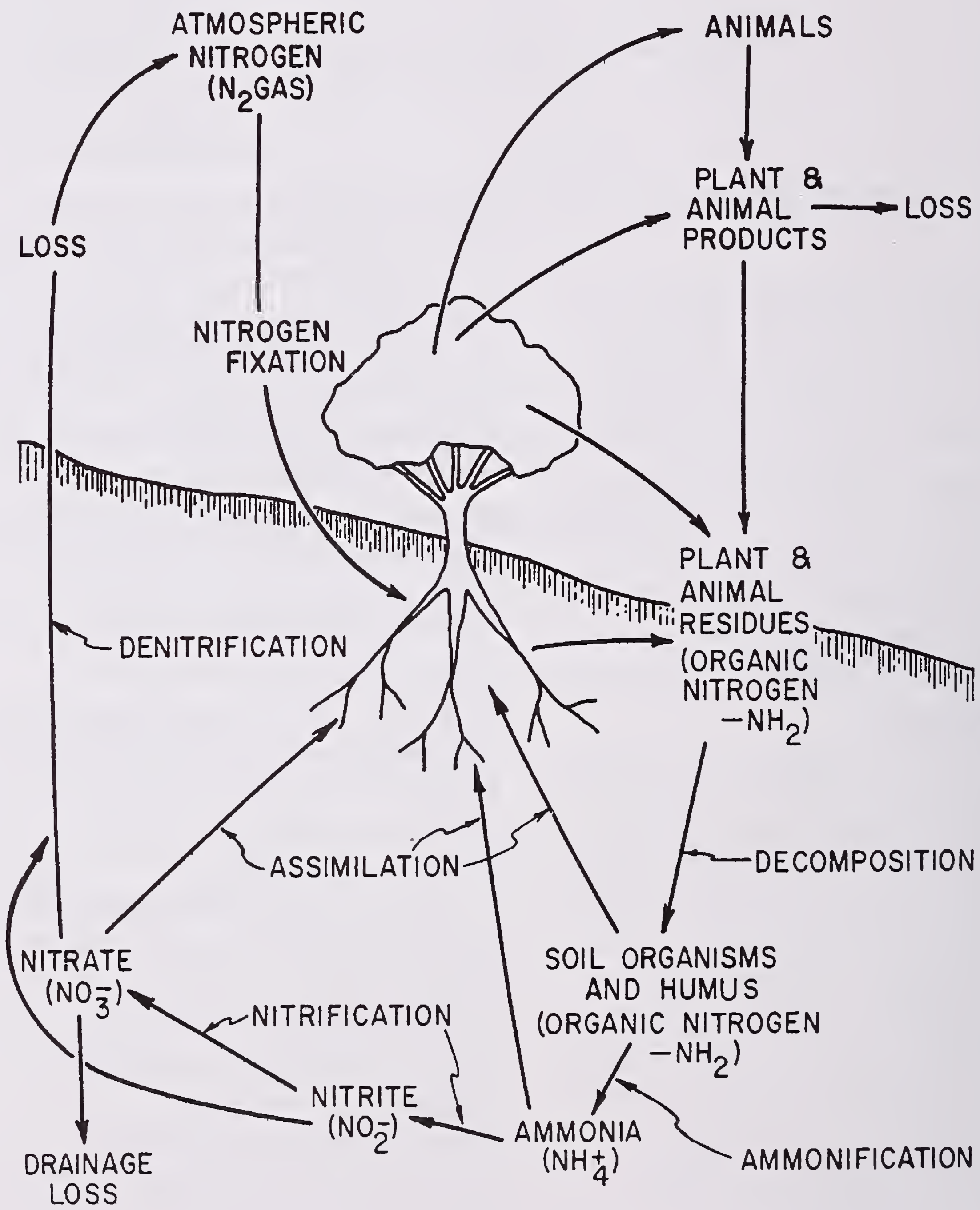

Figure 1. Nitrogen cycle in a forest nursery. Taken from USDA Forest Service Handbook on Soils - 2512.5 (June 1961).

The sources of pollutants of diffuse water bodies such as streams, lakes, and groundwater aquifers are often difficult to identify. When an industry or municipality releases wastewater into a surface body of water it is easy to identify the pollution source as a point source that can be modified. However, when looking for the source of contamination of bodies of water in agricultural landscapes it is difficult to pin-point a specific source. Instead, the source is leachate in water which is moving through cultivated fields, over logging roads and log decks, or from feedlots and is considered NPS pollution because of the diffuse nature of the source. Land management activities that reduce water movement, slow down or immobilize potential pollutants, while maintaining high productivity are called best management practices (BMP's).

BMP's are designed to limit the introduction of pollutants into the ecosystem or to intercept them as they move through the hydrologic cycle. Nutrient cycles are closely linked to the hydrologic cycle because nutrients move as dissolved or suspended solutes from one storage reservoir to the next. For example, nitrogen in organic matter in the nursery bed is released in decomposition as NH_4, a cation which can be adsorbed to soil particles (Figure 1). These insoluble cations can be transported with detached eroding soil particles which are deposited in surface water bodies. Or the NH_4 can be converted to NO_3 by bacteria. In this soluble anion form nitrogen is dissolved in the water and can be rapidly transported in the hydrologic cycle into plants, in unsaturated subsurface flow, or in the groundwater below the water table. It is this nitrogen which can make its way rapidly into surface water bodies or into shallow groundwater aquifers thus contaminating them above EPA MCL's of 10 mg/L (10 ppm). This brief example shows that pollutants can move as soluble or insoluble components of surface runoff to water bodies or can be leached as soluble components of unsaturated subsurface or groundwater.

There are numerous site characteristics which influence the movement of chemicals. For example soil texture can determine if soluble chemicals in the water will move rapidly through the profile as in a course sand or slowly as in a heavy clay in which there may be adsorption to the clay particles. Soil structure is a function of the gluing of soil textural particles into large aggregates which produce the pore spaces in the profile. Large macropores, which are found between aggregates allow water and solutes to move rapidly through the profile. Micropores, found mainly within the aggregates, allow only slow movement. Macropores also encourage aeration, root development, and micro- and meso-faunal activity which can increase the size of the macropores resulting in even more rapid water movement.

Soil organic matter is very important in providing adsorption sites for cations and for developing soil structure. There is often a positive correlation between soil organic matter content and soil nutrient content, soil structure, and therefore water movement. In soils with a very high organic matter content, above 10%, water movement may be hindered because of microsite topography. Under such conditions there is often no slope and water has no place to drain. As slope increases the rates of both surface and subsurface water movement increases. The depth to the water table also can play an important role in the movement of chemicals to the groundwater aquifer. A shallow water table means that nutrient rich water has only a short distance to move before reaching the water table. When the water table is deeper moving water is subjected to more microbial activity and plant root uptake whereby nutrients can be at least temporarilly immobilized in the biomass.

Finally, the vegetative cover on a site can greatly influence the movement of chemicals through the landscape. Under most native vegetation growing in areas of rainfall of 50 cm (20 in) or more there is little leaching of nutrients such as nitrogen. This is because the biogeochemical cycle is a tightly closed cycle where nutrients released by decomposition are rapidly taken up by the plant community and immobilized. When such areas are converted to cultivated crop production vegetative cover is only present for a part of the year. Both above- and below-ground biomass is greatly reduced because of harvesting and the annual nature of the crop. The below-ground biomass of annual crops is significantly less than that of perennial species exacerbating the problems of chemical movement. As a result there are long periods of time when the site is not occupied by living plants and leaching and

Table 1. Nitrogen fertilizer applications by state during 1992

STATE	APPLICATION SCHEDULE	FERTILIZER
1	Every 2 weeks @ 20 lbs/ac	Granular 34-0-0 or 21-0-0
2	Every 3 weeks @ 50 lbs/ac	34-0-0 or 21-0-0
3	Every 3 weeks @ 30 lbs/ac	34-0-0
4	Intiial application incorporated @40 lbs/ac Subsequently every 3 weeks @ 50-100 lbs/ac	34-0-0
5	Every 6 weeks @ 200 lbs/ac	34-0-0

surface runoff can carry both soluble and insoluble chemicals from the site. Cultivation also requires frequent entry on the site by large machinery which further complicates the problems by compaction.

Bareroot nurseries mimic cultivated agricultural fields. They lie fallow between crops, often over the winter and spring when low evaporation rates and high rainfall and runoff rates can occur. Because crops are removed almost every year, soil organic matter is often very low. This is especially a problem if nurseries are located on sandy soils which are often inherently low in organic matter. The high percolation and low organic matter content are conducive to conditions of rapid leaching. In heavier nursery soils, the frequent cultivation and bed forming activities destroy structure and result in very poor infiltration, puddling and surface runoff. In addition to these conditions, applications of fertilizers, which often exceed agricultural rates, can produce situations where large quantities of fertilizers may be leaving the nursery in surface water or groundwater.

Because the land area used by the nursery industry is relatively small in comparison to that in row-crop agriculture, regulatory agencies have not investigated nursery runoff. But because of the potential problems with NPS pollution the nursery industry should take a proactive role in determining the potential of NPS pollution from nursery sites and develop BMP's that will minimize the potential problems while producing high quality seedlings. To that end, the Hardwood Nursery Cooperative conducted an initial one-year study to determine the fate of nitrogen fertilizers under routine nursery management conditions. It was hoped that the results from that study could be used to develop fertilizer regimes that would produce target seedlings in the shortest time possible while minimizing the potential for surface and groundwater pollution.

METHODS

The general approach taken at each of the six nurseries where studies were conducted was to use present fertilizer regimes and a control with no nitrogen addition for the seedlings being grown. Fertilizer application rates and schedules at each of the nurseries is shown in Table 1.

The movement of NO_3-N through the first 1 m (3 ft) of soil was monitored using tension lysimeters. The tension lysimeters used were 2.54 cm diameter PVC pipes with porous ceramic cups on the bottom end. A cork with a tygon tube that reaches down into the ceramic cup is placed on the top end of the lysimeter. When samples are desired a negative tension is placed on the tube with a vaccum pump. The negative tension causes water to be pulled into the lysimeter from the soil solution. The water which is pulled into the tube is water which is held by tension in the micropores of the soil. Lysimeters were placed at 15 cm (6 in) and 1 m in the soil below replicated plots (Figure 2). A weather station also was installed at each experimental site to monitor rainfall and other common climatic variables. Water samples were collected at regular intervals during the growing season. Periodic water sampling continued 1-2 months after the last fertilizer applications were made. Seedling heights and diameters were measured twice per month on seedlings in perma-

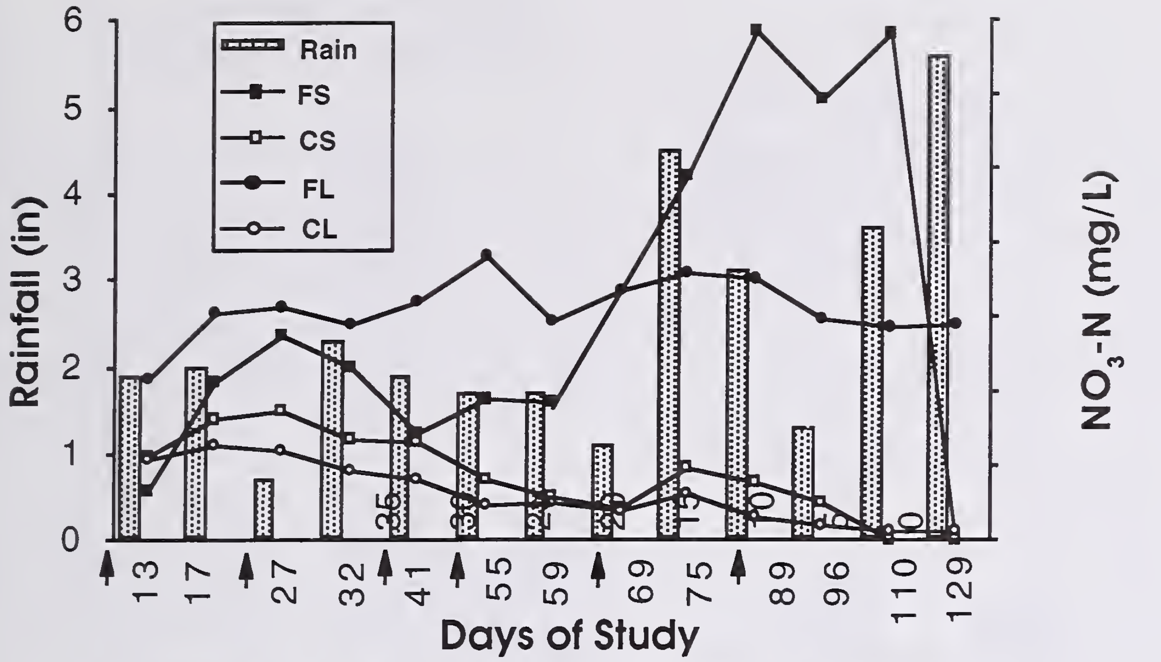

Figure 2. Nitrate-nitrogen concentrations and rainfall/irrigation data for State 1 between 5/21-9/24/92. Nitrogen fertilizer was added every 2 weeks at a rate of 22 kg/ha (20 lbs/ac) as 34-0-0 or 21-0-0. Nitrate-nitrogen concentrations: FS = fertilized - 15 cm (6 in); CS = unfertilized - 15 cm (6 in); FL = fertilized - 1 m (3 ft); CL = unfertilized - 1 m (3 ft).

nent plots and whole seedlings were removed from the plots at monthy intervals to determine biomass and nitrogen concentrations of the plant tissue.

WATER QUALITY RESULTS

In fertilized plots NO_3-N levels at 15 cm (6 in) were often higher than those at 1 m (3 ft) (Figures 2 and 3). In state 1 (Figure 2) NO_3-N levels at 15 cm (6 in) exceeded those at 1 m (3 ft) for about half of the first 130 days of the study. Increased moisture from rainfall seemed to move the surface applied nitrogen to the 15 cm (6 in) depth. At 1 m NO_3-N levels remained almost constant throughout the period suggesting that if NO_3-N had been removed from the water by the plants then the source of the water at 1 m represented more soil volume than the fertilized soil of the bed or block just above.

In State 2 (Figure 3) NO_3-N concentrations at 15 cm (6 in) were almost always higher than those at 1 m (3 ft). Once again, NO_3-N levels at 1 m remained almost constant throughout the period. At both depths and in both nurseries, soil water NO_3-N concentrations exceeded EPA MCL's for most of the growing season. In both nurseries concentrations at 15 cm (6 in) reached as high as 35 mg/L (ppm) while concentrations at 1 m (3 ft) ranged between 15-20 mg/L (ppm). This would suggest that the plant soil system was able to immobilize at least 15-20 mg/L (ppm) of NO_3-N between the 15 cm (6 in) and 1 m (3 ft) depths.

In the control plots NO_3-N concentrations at 15 cm (6 in) usually were the same as or below those at 1 m (3 ft) (Figures 2 and 3). NO_3-N concentrations at 15 cm (6 in) in the control plots of both States 1 and 2 were always below EPA MCL's. Because beds represent a relatively narrow soil surface width (1.2 m or 4 ft wide) soil water concentrations at the 1 m (3 ft) depths may have represented soil water percolating

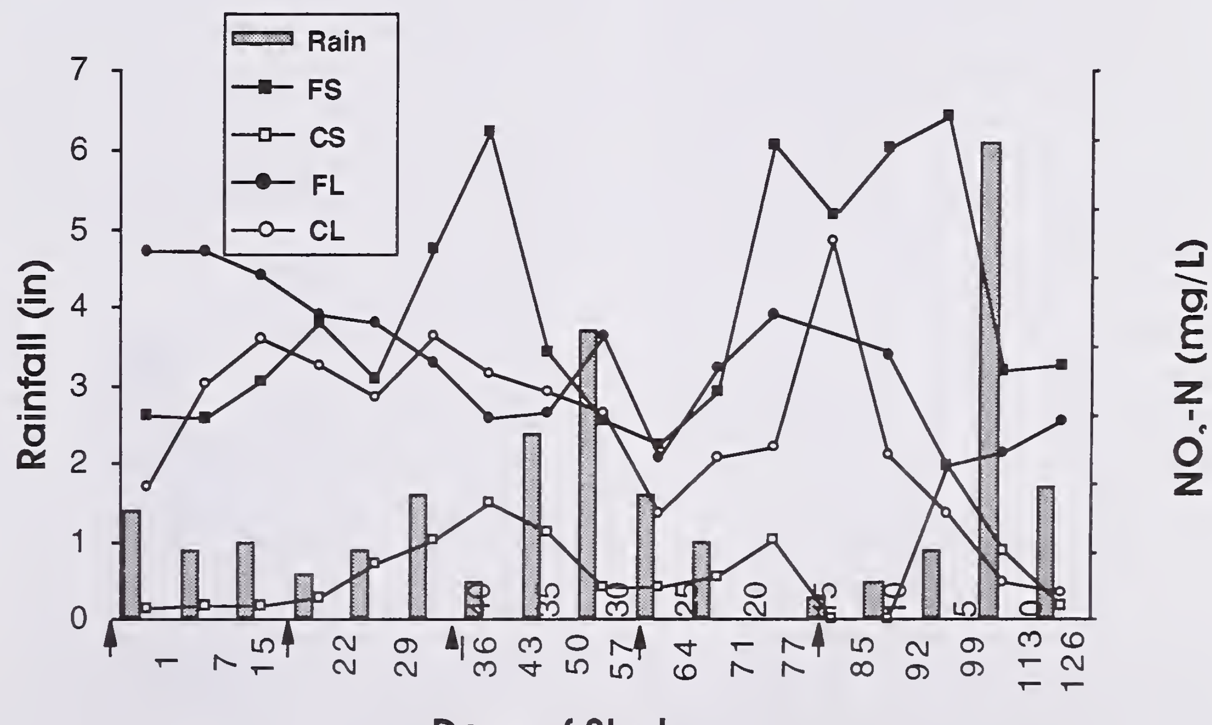

Figure 3. Nitrate-nitrogen concentrations and rainfall/irrigation amounts for State 2 between 5/21-9/24/92. Nitrogen fertilizer was added every 3 weeks at 56 kg/ha (50 bls/ac) as 34-0-0 or 21-0-0. Nitrate-nitrogen concentrations: FS = fertilized - 15 cm (6 in); CS = unfertilized - 15 cm (6 in); FL = fertilized - 1 m (3 ft); CL = unfertilized - 1 m (3 ft).

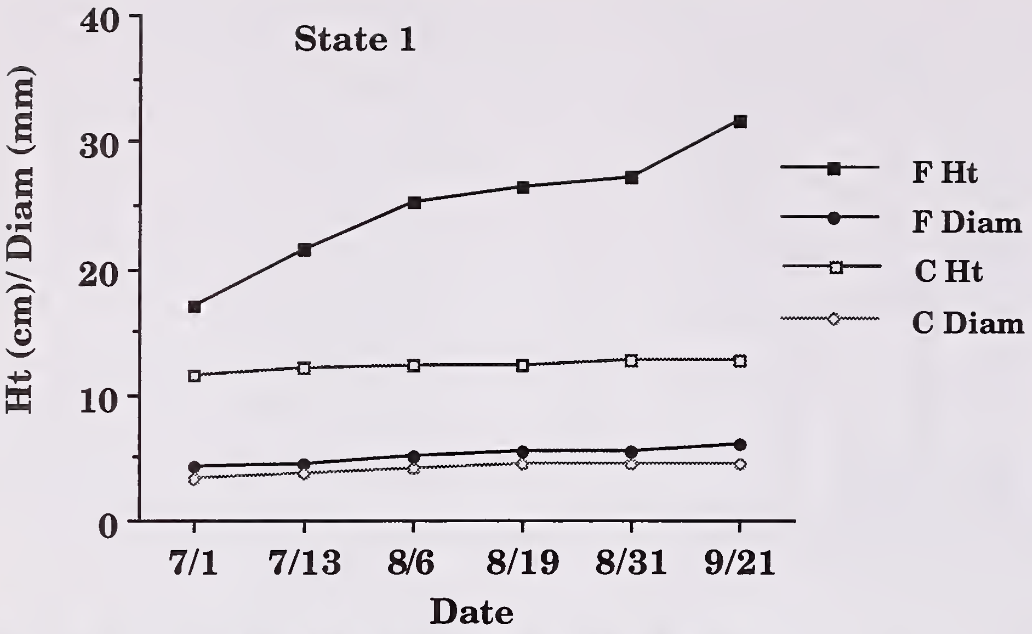

Figure 4. Height and diameter growth of red oak between 7/1/92 and 9/21/92 in State 1. Seedlings were fertilized with nitrogen fertilizer that was added every 2 weeks at a rate of 22 kg/ha (20 lbs/ac) as 34-0-0 or 21-0-0.

through several neighboring beds. As a matter of fact, in three states, NO_3-N levels at 1 m (3 ft) in the control plots were approximately the same as those in the fertilizer plots suggesting lateral movement of water at that depth. Figure 4 shows that phenomenon for State 2. This kind of data suggests that there was a lateral gradient for water movement that might be related to restrictive percolation rates or presence of the water table.

The NO_3-N at the 15 cm (6 in) depth responded more directly to rainfall or irrigation water inputs than those at 1 m (3 ft) again because the water at that depth was close to the source of both the water and the nitrogen. With each rainfall event a plume of NO_3-N could be seen moving through the nursery bed. It is speculated that most irrigation water was not sufficient enough to push the NO_3-N plume to 1 m (3 ft) depths. However, with high rainfall events, that nitrogen could be percolated to the greater depths.

Soil water NO_3-N concentrations were lowest in the fertilized plots of the States 1 and 3 that added the lowest levels of 34-0-0 in the study (Table 1). In those two states NO_3-N concentrations came closest to meeting the EPA MCL with concentrations lower than the EPA MCL for part of the growing season.

SEEDLING GROWTH AND NUTRIENT CONTENT

The red oak seedling response from State 1 will be used as an example of seedling responses that were identified in most states. Fertilized red oak seedlings averaged three times the height of control seedlings at the end of the growing season in State 1 where 22.4 kg/ha (20 lbs/ac) of 34-0-0 or 21-0-0 were applied every two weeks (Figure 4). The fertilized red oak seedlings in State 1 also had slightly larger diameters at the end of the growing season than control seedlings. The differences between the heights of the fertilized and unfertilized control seedlings indicates that height growth of seedlings could be controlled by fertilizer application.

Fertilized red oak seedlings averaged 2.3 times the number of leaves of control seedlings although dry weights of the leaves

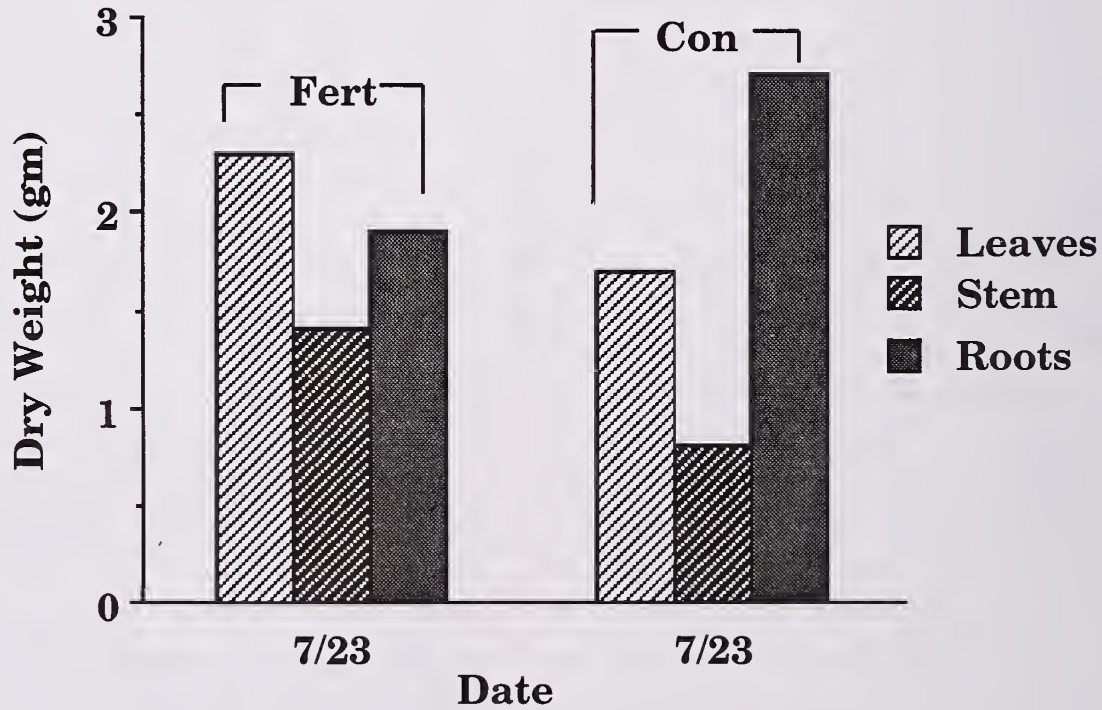

Figure 5. Dry weights of leaves, stems, and roots of red oak seedlings on 7/23/92 in State 1. Seedlings were fertilized with nitrogen fertilizer that was added every 2 weeks at a rate of 22 kg/ha (20 lbs/ac) as 34-0-0 or 21-0-0.

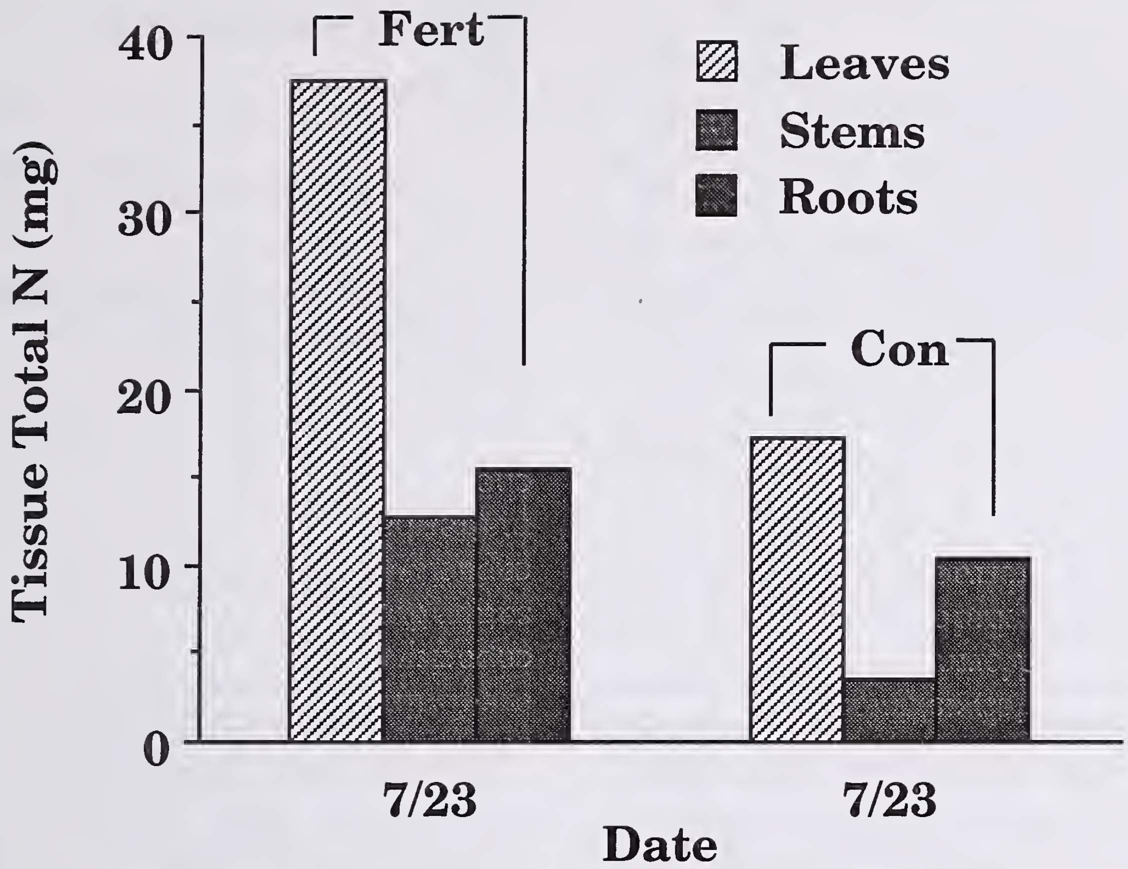

Figure 6. Average nitrogen content per red oak seedling in State 1. Seedlings were fertilized with nitrogen fertilizer that was added every 2 weeks at a rate of 22 kg/ha (20 lbs/ac) as 34-0-0 or 21-0-0.

for the fertilized seedlings were not 2.3 times heavier than those of the control seedlings. This would suggest that the leaves on the fertilized seedlings were smaller than those on the control seedlings (Figure 5).

Dry weights of control red oak seedling roots were 30% greater than those of the fertilized seedlings while stem weights of the control seedlings were about 60% of those for fertilized seedlings. The stem weight data seems to support the differences that can be seen in the height growth differences of the seedlings. The larger root mass of the control seedlings may may be indicative of stressed seedlings that have been seen under sites with low nutrient levels (unpublished data).

Nitrogen concentrations for the fertilized seedlings were greater than those for the controls; leaves 1.6% vs 1%, stems 0.9% vs 0.5%, and roots 0.8% vs 0.3%, respectively. Using these values the total nitrogen content per seedling can be calculated (Figure 6). The ratios of nitrogen content to total biomass for the leaves and stems are similar between the fertilized and control seedlings. However, the the ratios for the roots are reversed. The control seedling roots, although having a larger biomass than those of the fertilized seedlings, had only 66% of the nitrogen content of the fertilized seedlings. It would seem that roots can serve as a major sink for nitrogen, when it is available, during the the latter part of July when these measurements were made.

Some preliminary estimates of the fate of the nitrogen fertilizer can be made using the nitrogen contents found in the fertilized seedlings. If a density of 86 seedlings per m^2 (8 seedlings/ft^2) and a nitrogen content of 65 mg per seedling are assumed then approximately 56 kg/ha (50 lbs/ac) of N ended up in the seedlings. Using the rate of 134 kg/ha (120 lbs/ac) of N over the growing season that State 1 added, the lowest of all five states, 40% of the N ended in the plants and 60% ended elsewhere. Although these data for plant sequestering are supported by the literature (Eaton and Patriquin, 1990) they should be viewed very carefully. Simply saying that 60% of the N ended somewhere other than in the plants does not mean that it all ended up in the soil water as a potential pollutant. Under many situations a sizable amount of that N could have been denitrified by anaerobic bacteria and released to the atmosphere as harmless N gas. However, in agricultural systems 20-40% of the nitrogen applied as fertilizer may be lost from the site during the growing season (Power, 1981) and these losses increase with increasing fertilizer application rates (Barraclough et al. 1984). Since bareroot nurseries are intensively managed like agriculture fields it is possible that a large part of the nitrogen that is found at the 1 m (3 ft) depth may indeed reach the nearby surface and groundwater.

IMPLICATIONS

It is obvious that fertilizer is needed to produce target seedlings. An intensive production system where seedlings and their associated biomass and nutrients are removed every year or two can rapidly drain the reservoir of soil nitrogen. The nitrogen is also

being removed at a rate faster than is being naturally added to the system by microbial nitrogen fixation and atmospheric inputs. It is therefore necessary to supplement soils with nitrogen to produce high quality seedlings.

However, the results of this study would suggest that fertilizer is being added that is not being utilized by the plants and is therefore moving through the soil toward the groundwater. It is safe to assume that it is impossible to capture all or even most of the added nitrogen fertilizer in the plants under the best of conditions. There will always be some leaching of added nitrogen from a cultivated system which is devoid of well balanced plant-microbial-soil system. It would seem likely that fertilizer losses to the groundwater could be reduced if fertilizer additions were tied to plant demands for the nutrient. Thus, adding the same quantity of fertilizer at each application throughout the growing season does not seem to be biologically sound.

Fertilizer applications should be tied to the size and phenology or stage of growth of the seedlings (O'Hara, 1992). Applications to oaks might be timed to leaf expansion and the leaf linear phase of flushing when demand for nitrogen is greatest. For continuous growing species smaller amounts of nitrogen should be applied at the beginning of the season and steadily increased until it is desired to begin slowing growth in late summer. It also would seem feasible to add smaller amounts more frequently to the beds. To that end foliar applications of fertilizer or applications through the irrigation lines might be considered.

Nitrogen fertilizer might best be added as ammonium (NH_4) than as NO_3 and should never be added in the fall for over winter leaching. It might be time to again investigate soil organic matter management as organic matter contains approximately 5% nitrogen of which 2-5% is mineralized each year (O'Hara, 1992). If a soil contained 4% organic matter as much as 55 kg (120 lbs) of ammonium could be released each year.

It is recommended that nurseries consider routinely monitoring soil water nitrogen contents and try experimenting with reduced or differently spaced nitrogen fertilizer applications. This could be done by cutting the present rates of fertilizers in half and adding both the normal and reduced rates at twice the frequencies that are normally used. Monitor the NO_3-N in the rooting zone and minimize the concentrations except during the growing season. Although 10 mg/L (10 ppm) of NO_3-N is the EPA MCL a level of 5 mg/L (5 ppm) below the rooting zone should turn on the warning light (O'Hara, 1992). Sooner or later regulatory agencies will impose tough standards on the nursery industry if the industry is not willing to control itself. The potential costs associated with cleanup liability can be astronomical. Future legislation may require cleanup of contamination activities that were legal at the time they occurred (Feitshans, 1990). It is important that a proactive program be developed by nursery managers to identify the fate of added nitrogen fertilizers and to modify the rates of addition if and when potential problems arise (Landis et al., 1992).

ACKNOWLEDGEMENTS

The authors wish to thank Stu Pequignot and Al Stauder - Mason Nursery, IL; Jerry Grebasch, Roger Jacob, and Bruce Blair - Iowa DNR Nursery, IA; Miles Wiegand and Spenser Stone - General Andrews, MN; Bill Yoder - George O. White, MO; and Chuck Bathrick - Zanesville Nursery, OH for their support and assistance with this project. The Hardwood Cooperative has been supported by USDA Forest Service Focus Funding.

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Soil Management Plan for the G.O. White State Forest Nursery[1]

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Abstract – The George O. White State Forest Nursery has expanded, shifted its emphasis to producing a wider variety of species and has made changes in cultural practices. A need for soils information was recognized as a key tool on which to base important management decisions. Four major areas of management were selected for specific attention in this soils report. They are irrigation, fertility, species selection and pollution prevention.

INTRODUCTION

The George O. White Nursery was begun in 1935 with the purchase of forty acres by the U.S. Forest Service. This initial purchase became nursery blocks 1 through 6. Production of Shortleaf Pine seedlings for reforestation began soon after this purchase. With the outbreak of World War Two the nursery was closed and leased for crop production. In 1947 the Missouri Department of Conservation took over management, with the agreement that they would produce up to 2.5 million Shortleaf Pine seedlings for the National Forests in Missouri. In 1956, an additional 414 acres were added to the original purchase, most of which was not suitable for nursery applications. Approximately 30 acres of this acquisition were placed into production. This land was designated blocks 7 through 16. Ninety-nine acres were added in 1972 with production of seedlings beginning in 1977. This became blocks 17 through 22. In 1976 the Missouri Department of Conservation took title of the original 40 acres through a land exchange with the U.S. Forest Service. A final procurement of 201 acres was made in 1977. This acreage was utilized for seed production and wildlife planting. There is now a total seedbed surface area of 50 acres. The total acreage held is currently 748.

The production areas employ an irrigation system that has evolved over the years. A White Showers overhead system with one well was used during the initial years. A second well was added in 1963 and a third in 1983. The last of the White Showers system was dismantled in 1987 and a portable method of irrigation was adopted utilizing polyvinylchloride (PVC) pipes in all blocks but 17 through 22. These blocks have an underground PVC system with standpipes and sprinkler heads.

Since 1985, a wide variety of species have been planted in an attempt to meet the need for nursery stock. This is a continuation of the trend away from the production of purely forest species. Today the George O. White Nursery produces over 5 million seedlings yearly comprised of approximately 50 species.

MATERIALS AND METHODS

The George O. White Nursery is located near Licking Missouri, in the Northeast corner of Texas County. The county is located in South Central Missouri within the physiographic region known as the Salem Plateau. This area consists of Ordivician aged sedimentary rock between 438 and 505 million years old. The nursery lies on an area dominated by the Roubidoux Formation. This formation consists of sandstone with thinly interbedded chert.

The soils of the ridges and backslopes developed in residuum from sandstone and the majority are moderately deep. The soils of the footslopes and toeslopes are very deep and formed in colluvium and old alluvium. The terrace and floodplain soils are derived from old and young alluvium.

The climate of the area falls into the continental moist regime.

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[1] *Material presented during a tour of the Nursery as part of the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

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The summers range from warm to cool and the winters are cold. Precipitation averages approximately 39 inches per year and is evenly distributed among the four seasons. The evapotranspiration rate exceeds the natural rainfall during the main growing period making it necessary to utilize irrigation.

The study area consists of 22 fields encompassing approximately 100 acres. This tract is made up of roads, irrigation lines, field boundaries and seedling beds. Each field was treated as its own entity according to the management strategy used at the White Nursery. Soils information was collected on the seedbeds utilizing a 100'X 100' grid. Additional data was collected at 50 foot intervals when it was needed to separate soil types.

The grids were laid out from the southeast corner of each field using the sprinklers as reference points. Using these fixed points will allow the data to be recaptured in the future to compare the effects of use and management. At each of the sites the soil properties important to our study: surface and subsoil texture, horizon thickness, gravel content and drainage were recorded to a depth of 40 inches.

A representative profile was selected from each of the different soil types, excavated to a depth of 60 inches, described and sampled. These samples were sent to the Soil Characterization Laboratory at the University of Missouri for physical and chemical analysis.

A soils map was produced from the field work (see figure 1). This map will become a portion of a multidisciplinary data base for future management decisions.

Discussion

The ensuing section will elaborate on the soils and the areas of management selected as being the most important for the George O. White Nursery.

SOILS

The soils of the George O. White Nursery were mapped utilizing the important physical properties, as listed above, and the landform. Landforms separated included footslopes, low stream terraces and floodplains. Data on chemical properties, such as Cation Exchange Capacity, Organic Carbon, pH, etc, were collected through laboratory analysis, (see Appendix). Chemical properties were used for interpretive purposes and not to group soils.

Soils with similar physical properties on the same landform were placed in delineations called map units. Five map units were set up, named and labeled by number, (see figure 1). Differences in these map units occur mainly as a result of drainage, particle size and landform. Drainage ranged from well drained to somewhat poorly drained. The texture of the soils as determined from the particle size included sand, loamy sand, sandy loam, silt loam, loam, silty clay loam and clay loam. One map unit occurred on footslopes, three on low stream terraces and one on floodplains.

The following management discussions are based on the physical and chemical properties of the soils and are not separated by map units.

Species Selection

The determination of which species to plant, where and when, needs to be based on the physical and chemical properties of the soil in conjunction with the requirements of the plant. Soil properties affect germination, seedling survival and vigor, and timing of planting and harvesting.

Physical characteristics of the soil that influence these processes are drainage and available water capacity (AWC). Aluminum saturation, cation exchange capacity (CEC), pH and organic matter have an impact from a chemical standpoint.

Management Implications

The soils drainage will have the greatest affect on the germination of seeds and the survival and vigor of young plants.

Excessive moisture in somewhat poorly drained soils and a deficiency of moisture in somewhat excessively drained soils will affect seeds and plants. Subsurface artificial drainage and the use of raised beds will limit the affects of excess moisture. Diversions will control runoff from adjacent uplands. The irrigation system can be utilized to increase the moisture content under droughty conditions.

A soils ability to store and release nutrients to the seedlings is affected by its CEC. The CEC of a soil is discussed in the section on soil analysis and fertility. It is sufficient to say at this point that the lower the CEC the more difficult it is to maintain the nutrient level necessary for non-stressed growth. Increasing the CEC by increasing the organic

matter content in the surface to 3 percent will improve the nutrient suppling capacity of the soil.

Organic matter will help to alleviate the additional problem of surface crusting in the soils that have silt loam surfaces. This crusting phenomenon can lead to a decline in the number of seedlings that survive because the seedlings are unable to break through the crust.

High aluminum saturation (Al^{+++}) influences the rooting ability of young seedlings. Several of the soils expressed Al^{+++} saturation values which would prevent the roots from entering these horizons. The results would be less nutrient and moisture uptake. Application of lime (Ca^{++}) will lessen the affect of the Al^{+++} saturation. Of interest, two of the soils with the highest expression of toxicity were those soils that have been in production and under irrigation the longest.

A pH between 5.5 and 6.5 supplies the greatest benefits for the plants in regard to their needs and would assist in improving some of the other soil properties discussed above.

Scheduling of planting and harvesting can also related to the soil. The key here is drainage. Soils that are somewhat poorly drained or moderately well drained will have more scheduling limitations than those that are well or excessively well drained. Cultural practices completed when the soil is not at optimum moisture can contribute to the affects of other soil limiting factors.

SOIL COMPACTION

Some areas of the George O. White nursery have been under continuous cultivation for 20 to 45 years. Observations made during the data collection revealed zones of subsurface compaction from equipment traffic and soil manipulation. Soil compaction is unavoidable in this type of operation. The detrimental affects of compaction on crop production must be understood and considered in the management of soil tilth. Often it is "out of sight" and therefore "out of mind", making it more important to be aware of.

Soil compaction is the physical rearrangement of soil particles such that they are packed more closely together. This usually occurs in the surface layer of soils from machinery traffic during cultivation, planting, and harvesting. The size of the soil particles normally does not change, rather the pore space between them is reduced. This leads to reduced water infiltration, loss of aeration, impeded permeability, diminished root penetration and loss of nutrient exchange in the compacted zone.

Some of the more important symptoms of soil compaction problems are: perched water at or near the surface, increased runoff, poor plant emergence and thin stands, abnormal rooting patterns or uneven growth, and plant stress. These effects, on young plants, can be mistakenly identified as herbicide or fertilizer injury.

The soil investigations revealed a compacted zone around 7 to 9 inches beneath the seed beds. This condition exists in all soils but the Kaintuck (2B unit). The Kaintuck has a uniform, coarser particle size, which does not compact as much as soils containing a higher percentage of silt and clay. Compaction was also observed at a depth of 12 to 14 inches under the current and previous nursery bed paths.

The degree of compaction present in the 7 to 9 inch zone was not determined. This zone was consistent over the majority of the nursery. It is strong enough that it restricts water infiltration, as evidenced by gray color patterns indicating reduction of iron. Methods to accurately determine the degree of compaction are available. More commonly, observations of crop performance, root penetration patterns, water infiltration, and relative density when probing the soil are enough to determine the extent and level of compaction problems.

Management Implications

Once a compaction problem has been identified, steps can be taken to minimize the affect. Adding or maintaining organic matter levels in the soil is an important step to reduce compaction. Organic matter binds soil particles together into structural aggregates that resist being broken down by tillage or traffic. Other steps to minimize compaction are related to varying and timing equipment operations with moisture conditions. Moisture content has the greatest influence on the amount of compaction produced because it acts as a lubricant to the soil particles allowing them to be more easily rearranged.

IRRIGATION

The soil parameters that are important to irrigation are infiltration, permeability, texture and available water capacity. These characteristics of the soil determine the management of water applied by irrigation.

Infiltration is the parameter used to estimate the ease by which water can enter the soil. It is determined by surface characteristics of the soil. Some of the characteristics that affect infiltration are organic matter, structure, texture, moisture content, mulch, and surface sealing.

Permeability is the flux of downward water movement through the soil. It is related to the macropore characteristics as influenced by aggregation and structure. The permeability classes listed in the glossary describe the rates of movement of water through the soil.

Available water capacity is the ability of the soil to retain and supply water to plants. It is related to the micropore characteristics of the soil and is strongly dependent on texture. Medium textured soil, such as in the loam and silt loam classes, have the highest available water capacity. Factors that can affect the AWC are organic matter and compaction.

All of the above parameters are interrelated. An ideal parameter in one area may cause another to be less than ideal. Limitations can be minimized through careful management.

Management Implications

There are many possible calculations that can be used to help with management of irrigation. Many of the calculations are more agronomic than soil related. There are calculations for interval scheduling, rate of application, time of application, effective application, rate of infiltration, amount of water needed, and many more calculations of the kind. With specific relation to soils, the calculations are: recharge to maximum AWC; limit of permeability; and limit of infiltration.

The calculation for available water capacity is: AWC=(inches of water per inch of soil depth). The inches of water per inch of depth is based on texture. Coarse textured soils have low AWC, medium textured soils have high AWC, and fine textured soils have moderate AWC. By using one of several methods of calculating evapotranspiration, the amount of water removed from the soil is known. Subtraction from the total AWC gives the balance to be supplied by irrigation. It is important to remember to use only the depth of soil from which plant roots can obtain water.

Permeability is given in inches per hour. Once the amount of irrigation water applied per hour is known, it can be compared to the permeability to see if the irrigation is exceeding the ability of the soil to allow the water to move through. Rates that exceed the permeability can result in runoff and waste of water. Inversely, low application rates may not irrigate in a timely manner.

Infiltration calculations require experimentation to determine a constant for the soil type. Standardized experiments describe infiltration investigation procedures. Once the constant for a soil is determined, a formula is used to calculate how fast water can enter a soil. These calculations can show how fast water can be applied at a given set of beginning conditions and how long water can be applied at a given rate before runoff occurs.

On a practical basis, a manager can determine irrigation rates and effectiveness using AWC, remaining AWC after evapotranspiration, permeability, and rate of irrigation. As a manager gains experience, other calculations can be added and the entire system can be refined.

Modifications that have an affect on irrigation deal primarily with changes within the surface and soil horizon directly below. Permeability can be changed somewhat near the surface, but not at depth due to expense. Usually, the changes made to improve surface conditions will affect permeability.

Soil surface conditions can be changed dramatically. One of the more helpful practices is to increase the organic matter. Organic matter has a beneficial effect on AWC and permeability. Another practice that can help is mulching. A mulch protects the soil surface so the structure is not broken down by droplet impact. Sealing of the surface is also reduced. In addition, recent experimental information indicates that a moist surface may enhance infiltration. A mulch helps to maintain a moist soil surface. Tillage practices that

minimize the breakdown of the structure of the surface improves infiltration.

Surface texture affects infiltration. Coarse textured soils, such as sandy loam, have higher infiltration rates than fine textured soils. The texture is going to be relatively constant within the surface layer so irrigation needs to be managed for the surface texture.

That brings up the last area of modification: irrigation control. The intensity and frequency of water application should be managed as indicated by the soil. Experience is a valuable teacher and can be assisted by recording observations. The manager is the one that has to decide which factors are more important and how to reach the desired goals.

To sum up, the major factors affecting irrigation are infiltration, permeability, and available water capacity. These factors are interrelated and should be dealt with in a total system of management.

FERTILITY

The fertility of the soil is related to many factors. Focus will be placed on organic matter, low pH, cation exchange capacity, aluminum toxicity, and macronutrients.

The inherent fertility of the soil, or lack thereof, is from the parent materials. Parent materials that are high in desirable minerals impart fertile characteristics to the soil. The weathering process also affects minerals present in the soil. High rainfall, particularly coupled with high temperatures, can cause much of the original fertility to be leached from the soil. Such conditions can also allow the accumulation of undesirable minerals.

Organic matter is a factor of soil fertility. Higher amounts are typically good. Organic matter contains many nutrients that are released over time for plant use. Unfortunately, organic matter is easily lost. Management practices that maintain or increase organic matter are beneficial over the long term and should be of the highest priority.

The pH of the soil determines the availability of many minerals within the soil. Low pH increases toxicity of some minerals to plants. High pH causes problems with segregation of minerals necessary to plants. A pH ranging from 5.5 to 6.5 is desirable. The addition of agricultural lime will raise the pH if it is low. If the pH is too high, the addition of sulfur compounds can increase the acidity of the soil. Applications of fertilizers will increase the acidity of the soil over time. In addition, fertilizers are much more effective when pH is in the above range.

Cation exchange capacity is a measure of a soil's ability to provide nutrients to a plant. The CEC reflects the amount and type of clay in the soil. The organic matter also adds to the CEC. Normally, it is desirable to have the CEC dominated by basic cations such as Ca^{++}, Mg^{++}, and K^{+}. Within some soils, the CEC is pH dependant so that the CEC increases as the pH increases. Typically, the CEC is constant for a soil.

Among problems in soil fertility, the most serious are toxicity problems. Laboratory analysis indicates that some areas of the nursery have aluminum concentrations high enough to be toxic to plants. Often low pH allows the aluminum to become soluble and enter the soil solution. Aluminum toxicity can be ameliorated by liming to increase the pH and thus reduce the solubility of the aluminum.

Plants require macronutrients such as: nitrogen, phosphorus, and potassium. These minerals are easily added to the soil by commercial fertilizers. Sampling of the top 6 to 8 inches of the soil, and subsequent laboratory analyses of the soil samples, provides the best method of determining fertilizer needs. There are commercial laboratories that specialize in nursery soil analysis.

In summation, soil fertility comes initially from the parent material of the soil as weathered by the environment. The cation exchange capacity and organic matter are relatively constant for each soil and are not easily changed. Soil pH and macronutrient fertility can be manipulated, at least in the surface layer. The goal is to maintain high soil fertility.

POLLUTION PREVENTION

Following is a general definition of pollution prevention, as used by the USEPA:

Pollution prevention is the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes at the source.

Purchasing, storage, application and clean-up are all areas in which pollution prevention can be applied. The Missouri Department of Conservation, through their management practices,

already address several of these areas.

In the area of application, management of several soil properties can be utilized in developing additional practices to lessen the possibility of pollution from fertilizers and pesticides.

Surface runoff transports pesticides in solution or adsorbed to sediments. Filter strips, sediment basins, water breaks in drainage ditches and/or regulation of irrigation can reduce runoff losses.

Leaching is the process whereby pesticides are transported by percolating water below the root zone. Soil properties that need to be considered are texture, surface layer thickness, organic matter, structure and depth to water table.

Potential for leaching losses are inherent for the soils at the nursery. Increasing organic matter and its incorporation below the surface layer would increase the ability of the soil to retain pesticides in the rooting zone. Field 14, which had compost and additional fill added to the surface, showed the greatest degree of protection from leaching due to the ability of this material to lessen the downward movement of contaminants.

The texture, clay mineralogy, structure and depth to water table influence the soils natural permeability. Soils with a rapid or greater permeability or soils that have a water table near the surface have severe limitations for groundwater contamination. The Kaintuck and Moniteau soils have the greatest potential for pollution problems.

The greatest potential for pollution prevention is to have a knowledge of the soil, so as to apply chemicals appropriately and avoid over utilization of pollutants.

CONCLUSION

The soils of the nursery vary in their properties and in their response to management. Sound land use decisions are based on understanding soil properties and utilizing them in conjunction with management practices. This report provides a soil map, with detailed descriptions of the physical and chemical properties of each soil type. Discussion of species selection, compaction, irrigation, fertility management and pollution prevention are provided to supply information which will assist in determining modification of management practices or the soil resource to meet production goals.

ACKNOWLEDGEMENTS

The authors would like to thank the Soil Conservation Service for the use of their equipment and extend a special thanks to John Preston, Alice Geller and Bill Yoder for reviewing and making comments on our report.

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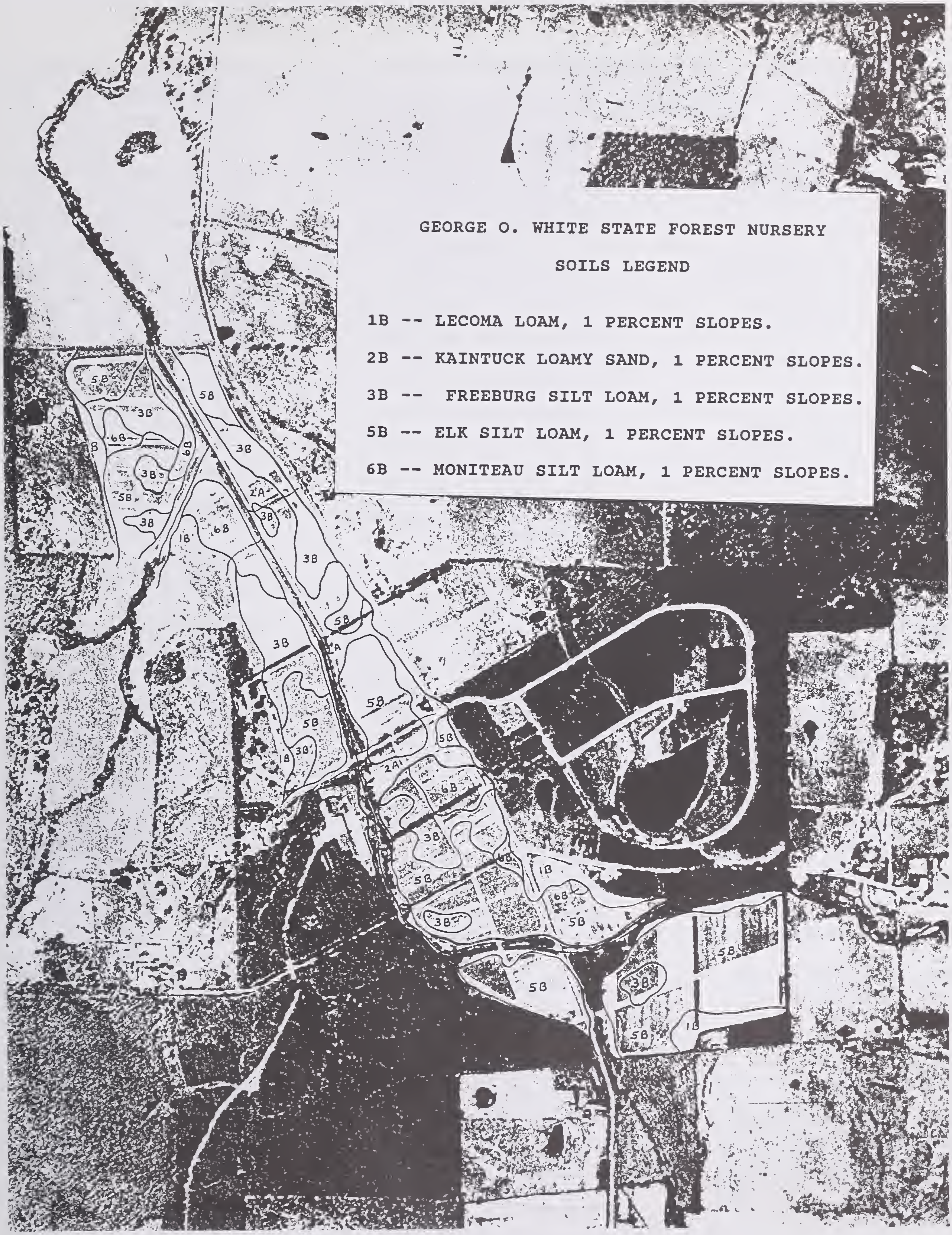

Figure 1 – Soils map of the G.O. White State Forest Nursery

APPENDIX A

Soil Analysis

The data presented in Table B represents the five typical soils found on the White Nursery. Along with this is the ancillary data from fields fourteen and twenty-two. An explanation accompanies the information.

Column 1: Soil name and map symbol.

Column 2: The soil horizon designation and the thickness of the horizon sampled.

Column 3 : The percent total clay. Particles <0.002mm. Used to determine textural class.

Column 4 : The percent total silt. Particles 0.002mm to 0.05mm. Used to determine textural class.

Column 5 : The percent total sand. Particles 0.05 to 2mm. Used to determine textural class.

Column 6 : The textural class of the soil horizon.

Column 7 : Ammonium Acetate extractable Ca, Mg, Na and K. Given in Meq/lOOq.

Column 8 : Cation exchange capacity. Given in meq/ lOOg.

Column 11 : The percent Aluminum saturation.

Column 12 : The percent base saturation.

Column 13 : The percent organic matter.

Column 14 : The pH.

Specific Uses

1 **Determination of water holding capacity:** the available water supplying capacity can be determined for the different soils by using the textural class for each horizon from column 6. The amount of available water can be determined to any depth below the surface. This data can assist in determining the amount of water a soil can supply to the seedlings. See Table A for average available water capacity as related to soil texture.

Table A

Inches per inch of soil	
Sand	.05-.09
Loamy Sand	.08-.12
Sandy Loam	.11-.15
Loam	.19-.22
Silt Loam	.20-.24
Silty Clay Loam	.18-.20
Clay Loam	.14-.17

2 **Indication of fertility:** The figures in column 7 will give an idea of the present availability of the cations listed. Through the use of the following formulas the pounds per acre for each cation can be determined.

(#/acre = Ca meq/lOOg X 20 X thickness cm X bulk density /2.2/2.471)

(#/acre = Mg meq/lOOg X 39 X thickness cm X bulk density /2.2 /2.471)

(#/acre = K meq/lOOg X 12 X thickness cm X bulk density /2.2/2.471)

3 **Cation Exchange Capacity:** This measurement is an indication of the readily exchangeable cations (Ca^{++}, Mg^{++}, and K^{+}) neutralizing negative charges in the soil. This exchange comes between the soil particles and the soil solution and supplies plants with the nutrients they need. Therefore this figure is usually closely related to soil fertility. The CEC figure is meaningful as far as plant growth, fertilizer additions and liming are concerned. The higher the CEC the greater its ability to hold and supply fertilizers and lime to the plants. The CEC of a soil is based on the percentage of clay, the type of clay and the amount of organic matter.

4 **Aluminum saturation:** This figure presents the percent of Al^{+++} in the soil solution. Anything other than very low concentrations of Al^{+++} are toxic to most plants. Sufficient lime will remedy the problem of aluminum toxicity. A pH of 6.0 or higher is an indication that calcium is sufficient.

5 **Base saturation:** This number is related to pH and fertility. For a soil of any given organic and mineral composition, the pH and fertility level increase with an increase in the degree of base saturation. Also the availability of the basic cations (Ca^{++}, Mg^{++}, and

K^+) to the plant increases with the degree of base saturation. A soil with 80 percent base saturation would provide cations to a growing plant far more easily than the same soil with a base saturation of 40 percent.

6 **Organic matter:** This is the percent organic matter present. The higher the organic matter the more natural fertility a soil has. It is also an indication of the amounts of cations or chemicals that can be adsorbed before runoff or leaching occurs. The higher the organic matter the greater the adsorption.

7 **pH:** The pH of an horizon is closely tied to the other lab analyses. pH is and indication of the H^+ ion activity in the soil solution or the acidity level of a soil. The pH has an effect on the production of plants due to its influence on the availability of certain nutrients. A pH between 5.5 and 6.5 will give the most desirable results depending on species.

8 **Soil attenuation capacity:** The soil attenuation capacity is the ability of the soil to lessen or dilute the downward movement of contaminants in the soil. It is represented by the Soil Leaching Loss Rating (SLLR). The SLLR is defined as: SLLR = (Surface Layer Depth) X (Organic Matter Content). A figure of 45 will provide adequate protection from leaching losses in the Kaintuck, Elk and Lecoma soils. A figure of 65 will furnish the needed protection on the Freeburg and Moniteau soils.

Table B

1	2	3	4	5	6	7				8	9	9	11	12	13	14
Soil Name and Map Symbol	Horizon and Depth	% Clay <.002	% Silt .002-.05	% Sand .05-2.0	Text Class	NH40Ac Extractable Bases				Sum Bases	Acidity meq/ 100g	CEC	Al Sat.	Base Sum	Org Mat	pH H2o
						CA	MG	NA	K							
1B Lecoma	Ap 0-9"	15.8	50.0	34.2	L	5.6	2.3	TR	.5	8.3	4.2	8.5	1	67	1.5	6.7
	2Bt1 9-12"	33.1	42.3	24.7	CL	3.8	2.7	0.0	.5	7.0	9.7	9.3	26	42	0.33	4.9
	2Bt2 12-22"	30.3	40.7	29.0	CL	1.6	1.9	TR	0.3	3.8	12.4	9.6	60	23	0.16	4.6
2B Kaintuck	Ap 0-12"	3.5	19.5	77.0	LS	2.2	0.0	0.0	.2	2.4	3.2	2.5	4	43	1.16	5.9
	C1 12-16"	3.1	9.9	87.0	S	1.0	0.0	0.0	.1	1.1	2.4	1.3	15	31	0.17	5.6
	C2 16-23"	1.0	3.0	95.9	S	.5	0.0	0.0	.1	0.6	1.1	.7	14	35	TR	5.6
	C3 23-27"	9.2	33.8	57.0	FSL	2.2	0.0	0.0	.2	2.4	4.5	2.7	11	35	0.66	5.3
	C4 27-41"	15.3	32.1	52.6	FSL	2.6	0.0	0.0	.2	2.8	3.7	2.9	3	43	0.5	5.6
3B Freeburg	Ap 0-9"	12.7	66.8	20.5	SIL	3.3	.8	0.0	.4	4.5	7.1	4.9	8	39	1.66	5.4
	Bt1 9-17"	21.0	71.4	7.6	SIL	2.8	1.2	0.0	.4	4.4	7.3	5.3	17	38	0.16	5.1
	Bt2 17-25"	25.5	68.1	6.4	SIL	3.3	1.2	0.0	.4	4.9	8.8	7.0	30	36	0.16	4.9
	Bt3 25-37"	20.4	70.4	9.2	SIL	2.5	1.1	TR	.3	3.9	8.7	6.3	38	31	0.33	4.9
	Bt4 37-54"	16.9	59.4	23.6	SIL	1.7	1.2	TR	.2	3.1	7.4	5.3	42	30	0.33	4.9
	Bt5 54-62"	5.9	25.3	68.8	COSL	.7	.4	0.0	.1	1.2	3.1	1.9	37	28	0.16	4.9
5B Elk	Ap 0-9"	14.4	74.1	11.5	SIL	5.4	1.5	TR	.4	7.3	5.2	7.4	1	58	2.0	5.9
	Bt1 9-16"	21.1	74.1	4.8	SIL	4.5	2.0	TR	.2	6.7	5.2	6.8	1	56	.83	5.9
	Bt2 16-38"	25.5	71.3	3.3	SIL	4.2	1.2	.1	.3	5.8	7.3	6.3	8	44	.50	5.2
	Bt3 38-61"	22.3	73.2	4.6	SIL	3.8	1.6	TR	.2	5.6	7.7	6.4	13	42	0.33	5.2
6B Moniteau	Ap 0-12"	16.4	66.7	16.9	SIL	6.5	1.2	0.0	.4	8.1	6.9	8.1	0	54	2.3	6.2
	E 12-21"	16.6	79.6	3.8	SIL	1.9	.4	.1	.2	2.6	7.1	5.3	51	27	0.16	4.7
	Bt1 21-35"	20.0	76.6	3.4	SIL	1.4	.8	.2	.1	2.5	10.3	7.0	64	20	0.16	4.8
	Bt2 35-45"	24.2	58.4	17.4	SIL	2.6	1.9	.6	.2	5.3	11.0	9.0	41	33	0.33	4.9
	Bt3 45-55"	25.4	71.4	3.2	SIL	3.6	2.8	.9	.2	7.5	11.1	10.6	29	40	0.33	4.9
	Bt4 55-61"	27.5	68.1	4.4	SICL	3.5	2.7	.9	.3	7.4	9.3	9.3	21	44	0.33	4.9
Field #14	Ap1 0-8"	11.9	66.1	22.0	SIL	6.8	.8	.1	.6	8.3	6.4	8.4	–	56	3.5	6.0
	Ap2 7-16"	12.1	65.9	22.0	SIL	5.3	.4	TR	.6	6.3	6.2	6.5	–	50	3.0	6.0
	Ap3 16-24"	13.5	72.1	14.4	SIL	1.9	.8	TR	.4	3.1	4.6	3.3	–	40	1.16	6.0
Field #22	Ap1 0-8"	12.4	54.7	32.9	SIL	5.9	1.6	TR	.2	7.7	4.6	7.7	0	63	1.66	6.7
	Ap2 8-17"	13.6	60.0	26.3	SIL	3.8	1.2	TR	.2	5.2	4.7	5.2	0	53	1.0	6.2
	Ap3 17-24"	9.1	38.1	52.8	FSL	2.7	.4	TR	.1	3.2	5.6	3.4	6	36	1.0	5.4

Soil Compaction: Causes, Effects, Management in Bareroot Nurseries[1]

R.R. Allmaras, J. Juzwik, R.P. Overton and S.M. Copeland[2]

Abstract – Although soil compaction appears as a simple reduction in soil volume, the effects on the soil are far more complex and influence many processes. Perhaps the most significant impact of compaction is the change in soil water relations which in turn, has many impacts on plant root growth and health. This article describes compaction and how to locate and measure it in bareroot nurseries. Because organic residues can significantly reduce compaction and its effects especially in a long term soil management program, the mechanisms of residue effects on compaction are discussed. Guidelines for preventing and/or managing soil compaction in nurseries are also presented.

INTRODUCTION AND OVERVIEW

Soil compaction is associated with nearly all field operations (wheel traffic, tillage with various implements, undercutting, and lifting) in bareroot nurseries. Operations conducted under wet soil conditions, in particular, favor compaction and soil structural damage. Establishment and use of permanent tractor paths in nurseries reduces the compactive effect of wheel traffic, but other nursery operations must also be scrutinized carefully for production of compacted soil layers.

Soil compaction can be beneficial or adverse depending on its severity and location in the nursery beds. Evidence of detrimental compaction can be elusive, but may be suspected in bareroot nurseries when water ponds on the surface, seedling vigor is poor, and root diseases are abnormally severe or appear to increase (Duryea and Landis, 1984).

Compaction is defined as the rearrangement of aggregates and primary particles into a state of higher bulk density and lower porosity when a load (or stress) is applied to a soil (Warkentin, 1984; Bradford and Gupta, 1986). The first impact of compaction is the loss of pore space between aggregates (interaggregate pore space) as the soil volume is decreased (Cruse and Gupta, 1991). Smearing or crushing of individual aggregates (intra-aggregate pore space) occurs in the next stage as the soil volume is reduced more. The loss of interaggregate pore space has a major effect on water infiltration and drainage, gas exchange and aeration (oxygen diffusion), mechanical resistance to root penetration and proliferation, heat movement, and biological activity of both soilborne pathogens and the host organism (fig. 1; Allmaras et al., 1988a). When individual aggregates are crushed only the smallest pores remain and the biological environment deteriorates even more.

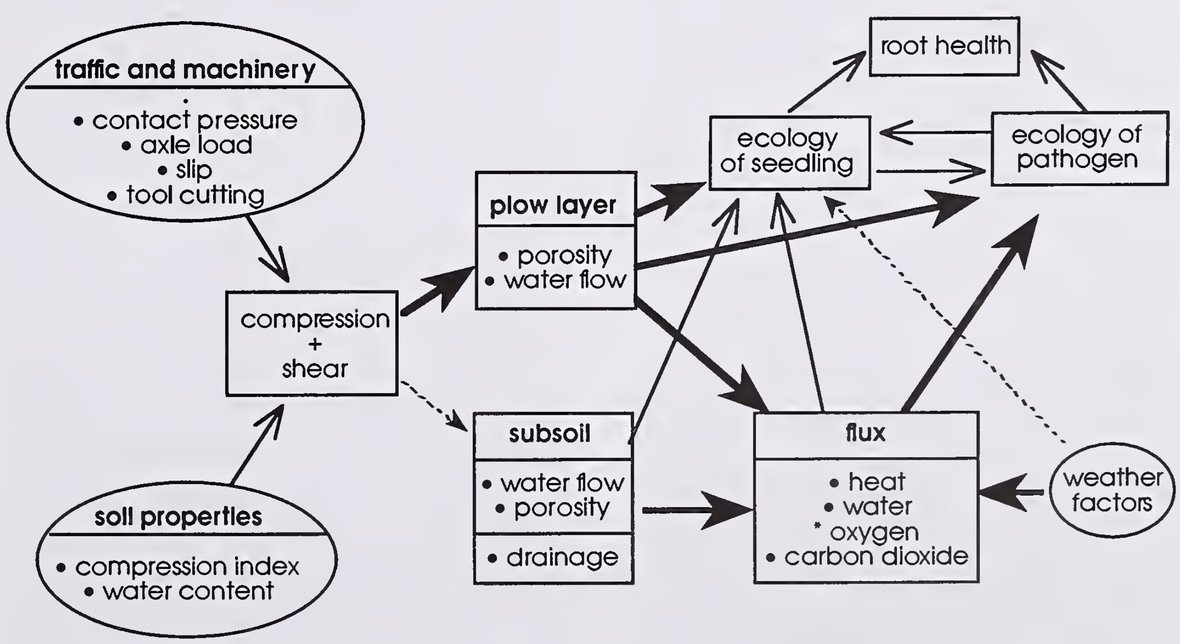

Figure 1. Relationships between soil compaction and root health; a diagrammatic guide.

[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

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Once aggregates breakdown and only very small pores dominate, regeneration of favorable structural conditions may take years (Hakansson et al., 1988). The extent and severity of compaction are therefore important considerations due to their effects on physical, biological, and hydrological processes.

An alternative explanation for compaction is that the rearrangement of aggregates and primary particles changes the total pore space, pore size, pore continuity, and soil strength because of the solid-to-solid contact (Gupta et al., 1989). These changes of soil properties can then be used to predict a response of processes like water flow, aeration status, heat flow, and mechanical resistance to rooting.

The above definition of compaction involved the action of an applied load or stress. The change induced in the soil is considered as a strain. Soil mechanics specialists then consider axle load, contact pressures, wheel slip, and tool cutting or sliding as stress factors — compression and shear are the major modes of strain (fig. 1).

Along with observations on seedling growth and soil drainage, soil measurements and a log of field operations are needed to discover compacted areas and layers, their cause, and to take remedial action. Field management to reduce or minimize soil compaction can be linked somewhat to general knowledge about stresses imposed by traffic, tillage machinery, and other operational equipment/practices. Soil water content at the time of field operations ranks high in importance along with axle load, contact pressure, and slip as factors that contribute to adverse compaction. Organic matter management and additions are used for many purposes in bareroot nurseries (Davey, 1984), but nursery managers should examine more closely the influences of organic residues and organic matter on soil structure, reduction of compaction, and associated effects on soil drainage and aeration.

The objectives of this paper are to discuss the effects of compaction, where and how to locate and measure compaction in the nursery field, the interaction between organic matter and compaction, soil ecological considerations, and implications for soil management in bareroot nurseries.

PROBLEMS

Problems induced by excessive compaction are runoff, soil erosion, slow infiltration and soil crusting, impaired or delayed internal drainage, decreased soil water storage, shallow and sparse plant rooting, reduced nutrient and water uptake, accelerated denitrification, production of toxic materials due to soil reducing conditions, fewer field days, and more root disease from pathogens such as *Pythium, Phytophtora, Aphanomyces, Fusarium* and *Rhizoctonia* spp. Most of these problems are linked to adverse water relations caused by retarded infiltration, less air-filled pore space, and impeded water movement. Many of these problems are discussed in review articles, for example: a) root-system centered response to soil compaction (Taylor and Brar, 1991; Voorhees, 1992), b) gaseous flux and aeration responses to soil compaction (Allmaras et al., 1988a; Smucker and Erickson, 1989), c) oxygen relations in root environment (Drew, 1983), and d) mechanically impeded root growth (Bathke et al., 1992).

BENEFITS

There are instances where moderate, deliberate compaction of soil is beneficial. Seed-soil contact (Hadas, 1982) is routinely improved by packing soil around the seed. This contact is necessary to transmit water to the seed for germination. Ideally, such compaction should occur so that the soil immediately below the seed has a higher strength than the soil above the seed. A moderate amount of compaction in the plow (Ap) layer prompts some agronomic crops, such as peas and soybeans to develop more fibrous root systems that are less dominated by a tap root (Voorhees et al., 1975; Russell, 1977; Smucker, 1993). However, excessive compaction results in a more branched root system where the primary axis roots do not respond by growing downward according to geotropic response. Moderate compaction may also encourage clod formation in formerly compacted zones such as old wheel tracks (Voorhees et al., 1978). Tillage actions which form these types of clods also serve to incorporate crop residue into them (Staricka et al., 1992). A moderately compacted soil with a surface mulch is considered best for reducing evaporation in seedbeds (Hadas, 1982) and during summer fallow (Pikul et al., 1985), and when field traffic is

controlled, compaction of traffic paths results in improved vehicle traction (Swan et al., 1987).

LOCATING AND MEASURING COMPACTION IN THE FIELD

Several methods are available for locating and measuring soil compaction. These include methods which can be used in the field to measure compaction after it has occurred as well as laboratory tests that evaluate soil responses to dynamic or static loading.

Field Methods

Field methods most frequently used to assess soil compaction involve measuring soil bulk density or soil resistance to penetration.

Soil bulk density is the dry weight of soil that occupies a known volume of solids plus water plus air. It is expressed as grams of oven-dry soil per cubic centimeter (g/cm^3). Within a given soil, bulk density is a measure of how closely soil particles are packed, so that relatively higher bulk densities are an indication that compaction has taken place. However, differences in bulk density between different soil types cannot be directly related to compaction effects because pores may have different sizes or different connectivity.

Various methods of measuring soil bulk density, including coring, excavation, clod density, and gamma radiation have been reviewed (Blake and Hartge, 1986). Improvements in the coring method (Allmaras et al., 1988b; Doran and Mielke, 1984) facilitate locating and measuring thin, compacted layers common in tilled fields. An especially simple and useful modification of the excavation technique is the compliant cavity (Bradford and Grossman, 1982). The clod density method may be helpful in evaluating the effect of historical practices on clod or aggregate density. These effects may be negative (excessive compaction or fragmentation) or positive (use of manure or other organic amendments).

Cone penetrometers are commonly forced through the soil to measure soil penetration resistance (Bradford, 1986). Penetration resistance is a pressure (a vertical force divided by the basal area of the cone) expressed in units of megapascals (MPa). Cone shape and rate of advance into the soil must be specified. The most popular penetrometer is the "Corps of Engineers" specification with a cone basal area ranging from 1.3 to 3.2 cm^2, a driving shaft 46 cm long with extensions, and a cone with a 30° included angle (Bradford, 1986). Penetration resistance represents the combined effect of cohesive and frictional characteristics of the soil. Therefore, soil water content and soil type, as well as soil density, affect soil penetration resistance. This means that differences in soil penetration resistance between either different soil types or the same soils at different water contents must be adjusted to measure compaction effects. For this reason penetrometer measurements should have associated soil water measurements. The ease and rapidity with which penetration tests can be made permits many of these measurements to be taken within the area of interest.

Two criteria have been suggested to determine whether compaction is significantly affecting root growth rate, and another criteria has been suggested to determine if compaction is significantly affecting soil structure (Gupta and Larson, 1982). The first two criteria, 1) an excess of 2 MPa resistance to soil penetration as determined by a cone penetrometer, and 2) less than 10 percent air-filled pore space, can be combined to estimate the effects of anaerobic conditions and mechanical impedance on root growth rate. The other criterion is the combination of applied stress and soil water content needed to begin the consolidation of soil aggregates after the interaggregate pore space has been removed by increasing compactive stress.

Neither bulk density nor soil penetration resistance provide any information about the geometric arrangement of soil particles or pore-size distribution. However, soil structure and porosity are critical properties influencing air and water flow in soil, and must often be measured directly to determine how soil layers of different densities or penetration resistance affect these properties.

The following examples show field compaction and illustrate the variety of methods that can be used for description. A hand-held cone penetrometer was used to measure compaction profiles (fig. 2) in a clay loam subjected to four different types of primary tillage for 10 years (Swan et al., 1987). Resistance was measured con-

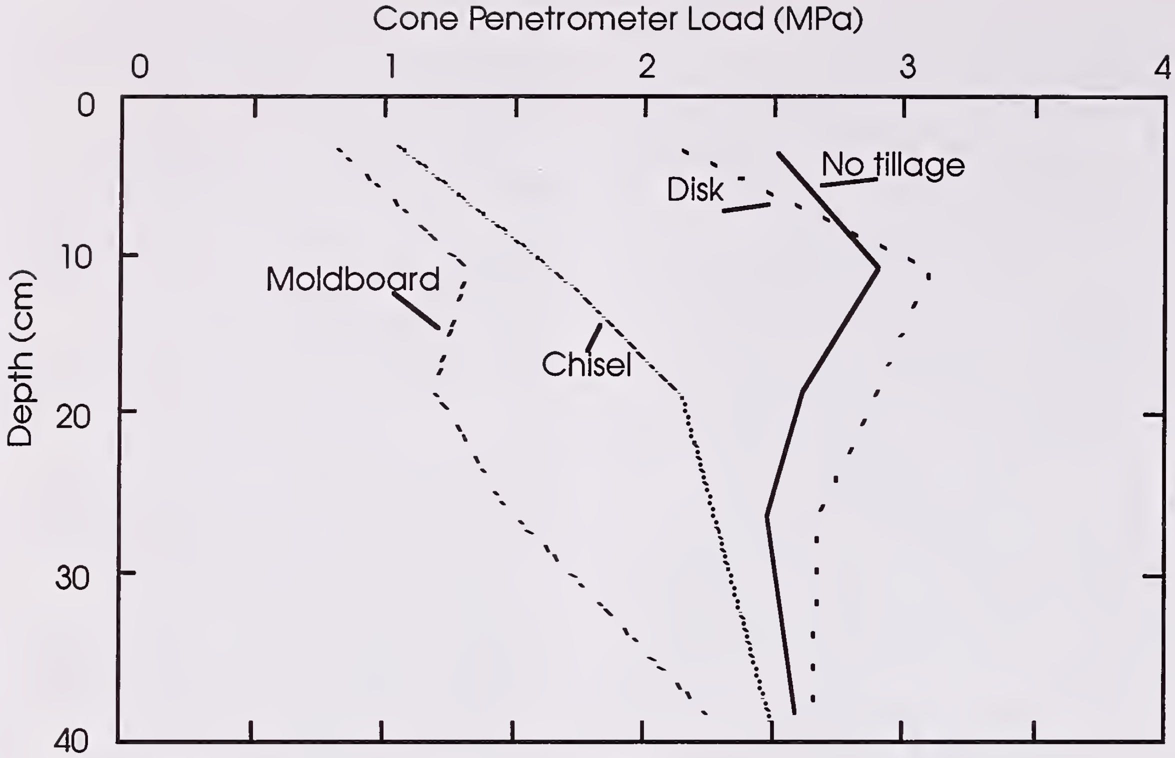


Figure 2. Soil compaction produced by primary tillage tools in a long-term tillage system and measured with a cone penetrometer (after Swan et al., 1987).

tinuously as the penetrometer was forced through the soil to a depth of 38 cm. Soil resistance in the moldboard plow treatment approached 2 MPa (which is considered a critical load for rooting) at about 28 cm, or the plane between the Ap layer and the untilled subsoil. The continuous disk treatment showed a disk pan at 10 cm, the common depth of penetration for a disk. The no-tillage and disk treatments had about the same resistance profile, except that the no-tillage treatment did not have the disk pan and had not been disturbed in the 2 to 6 cm depth range. Both the moldboard and chisel treatments had less compaction than the other two treatments. The moderately compacted zone at 10 cm in the moldboard treatment may have been caused by surface traffic, but the resistance profile did not identify a plow pan usually found at 25 to 30 cm in this soil (Logsdon et al., 1990). Resistance profiles for the chisel, no-tillage, and disk treatment should all be alike in the depth range of 15 to 38 cm. The differences between these treatments may have been due to different soil water contents (Bradford, 1986) which where not measured; as was mentioned earlier, cone penetrometer loads can be misleading unless soil water profiles are measured to make a correction. Some researchers avoid the problem of variable soil water content by making measurements in wet soil using a more sensitive cone penetrometer (Bradford, 1986).

Bulk density profiles in fig. 3 illustrate individual and interacting effects of axle load and soil water content on soil compaction — both severity and depth of compaction. An axle load of 4.5 ton is normal for medium sized tractors; a partially loaded combine has a 9-ton axle load; and a large grain wagon fully loaded may have an 18-ton axle load. In the "dry" regime soil water content in the upper 20 cm was in the range where compaction

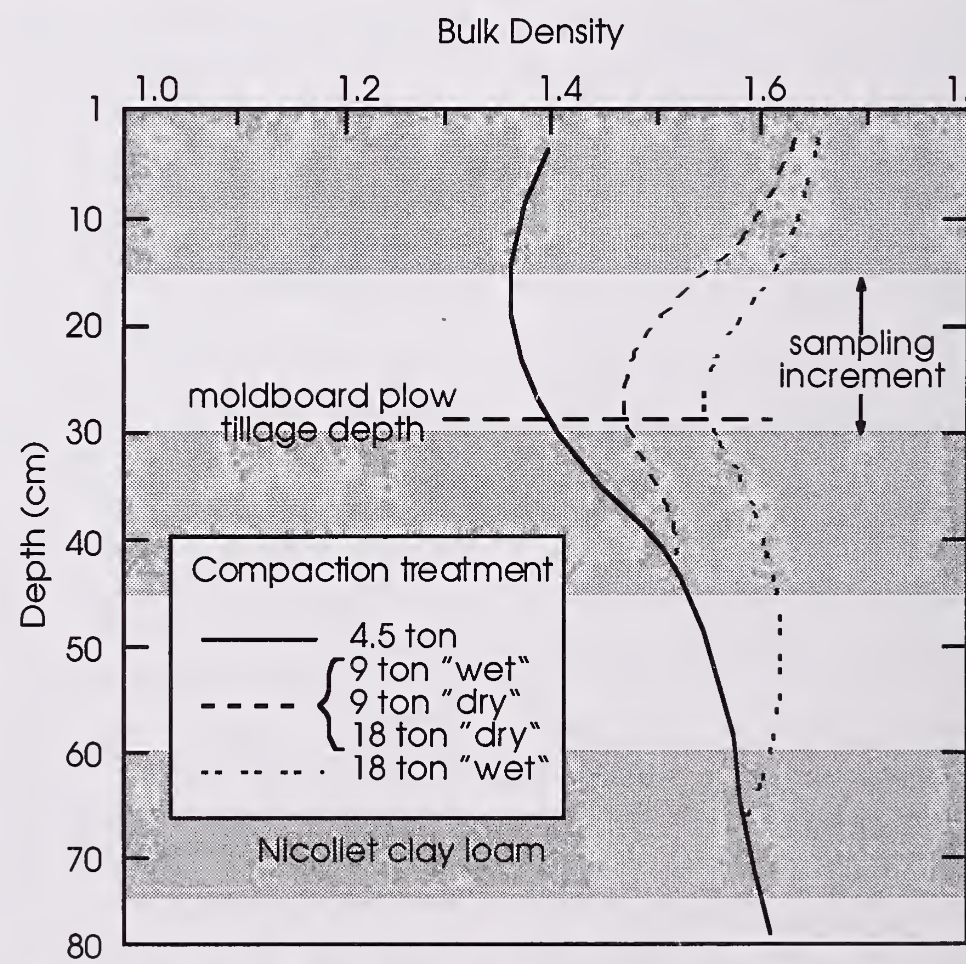


Figure 3. Compaction produced by different axle loads applied where the soil water regime was "wet" or "dry" (after Voorhees et al., 1986).

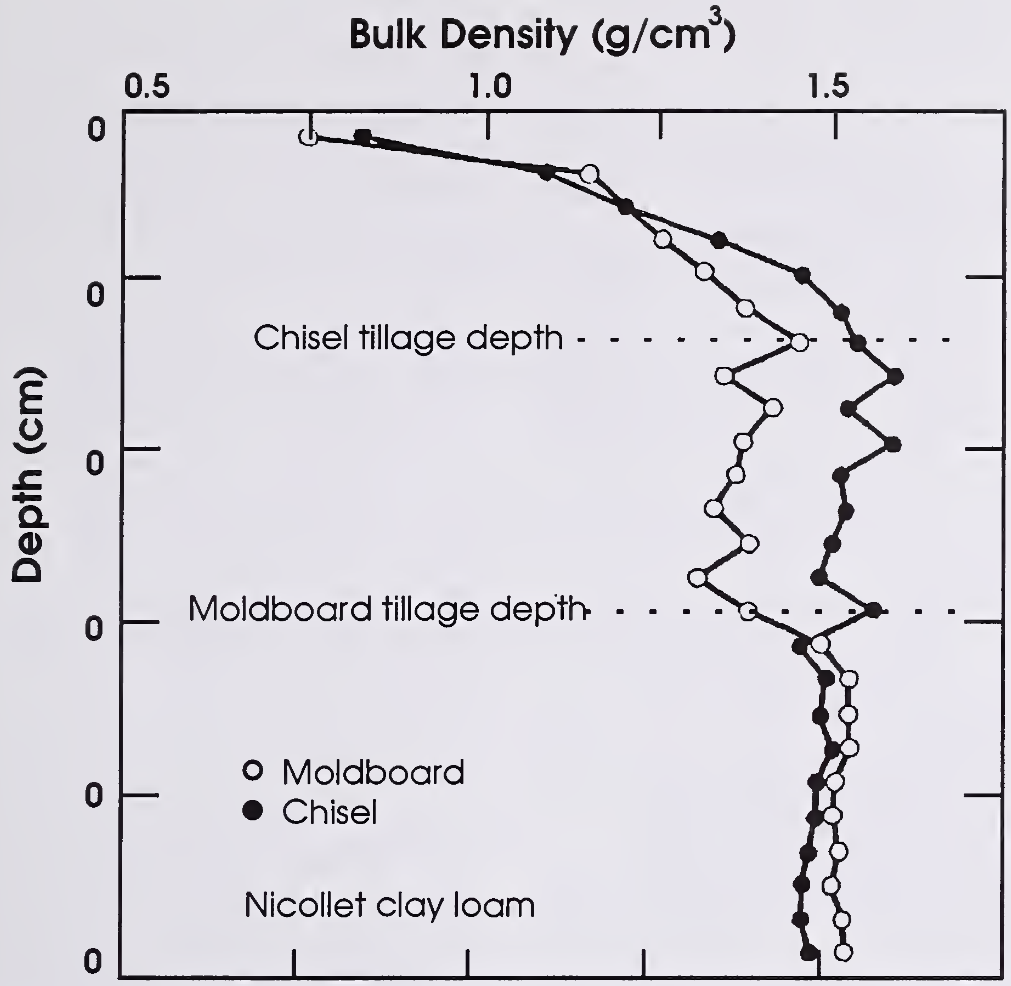


Figure 4. Changes in bulk density characteristic of moldboard compared to chisel plowing (after Staricka et al., 1990).

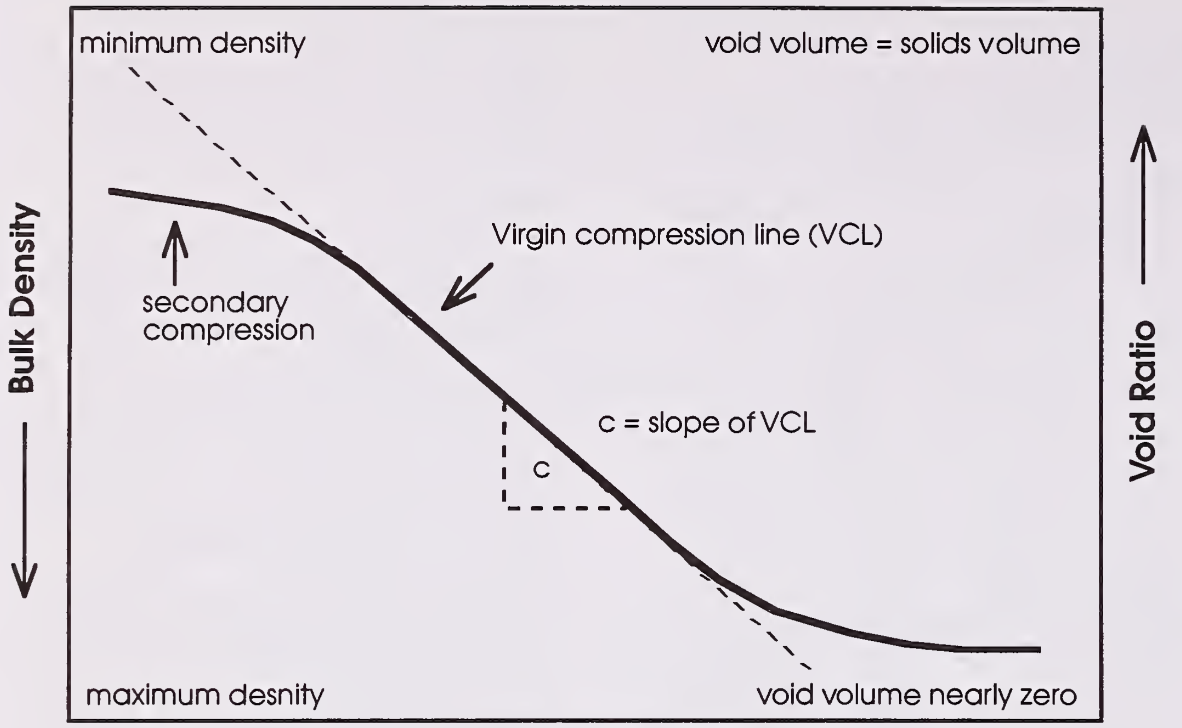
would be severe, and the rest of the profile was near the water content at permanent wilting where resistance to strain is a maximum. In the "wet" regime the whole 80-cm profile was wetter than the water content expected for most severe compaction. One bulk density profile explained compaction from the 9-ton axle load for both soil-water regimes and the 18-ton axle load on the "dry" regime. The maximum depth of compaction was about 30 to 40 cm. An additional increment of compaction was produced by the 18-ton axle load on the "wet" soil — this compaction extended to nearly 60 cm. The lower bulk density at 25 to 40 cm is characteristic in the tilled Nicollet clay loam because frequent soil rupture by tillage has rendered the soil in the Ap layer more susceptible to compaction, and overburden from historic glaciation has compacted the subsoil.

Bulk density profiles in fig. 4 compare the influence of primary tillage, after the same secondary tillage had penetrated no deeper than 10 cm. Soil cores were purposely not taken where there was traffic during secondary tillage. Moldboard plowing produced a lower bulk density than chisel plowing in the Ap layer extending from 6 to 30 cm. The marked increase in bulk density of the moldboard treatment at 30 cm is a characteristic that defines the depth of penetration while chiseling only shows a marked decrease of bulk density above its depth of penetration. Moldboard plowing often shows a plow pan near the maximum penetration depth, and can be either from the current tillage or a residual from operations of a previous year (Logsdon et al., 1990).

Figures 3 and 4 also illustrate bulk density profiles obtained by two different methods of core sampling. Bulk density profiles in figure 3 were obtained using a tractor-mounted hydraulic coring device (nominal core diameter of 4.8 cm and length of 15 cm). Profiles in figure 4 were obtained using a hand sampler (core of 18 mm diameter and 20 mm long). Each profile in figure 3 is a composite type average of 8 cores — those in figure 4 were obtained from 15 cores. The smaller cores and the 2-cm increment of depth used to develop the profiles in figure 4 nearly always detect depth of tillage and associated tillage pans even when they are no thicker than 4 cm, and these thin tillage pans can impede water movement (Allmaras et al., 1988a). In contrast, the larger cores used to develop the profiles in figure 3 rarely distinguish tillage pans produced by either traffic or tillage tools.

Laboratory Methods

Several laboratory procedures can be used to evaluate how factors such as machinery loading, soil water content, and soil physical properties can be varied to control compaction. The Proctor test (ASTM, 1979) uses dynamic soil loading to measure the maximum soil density produced per unit of energy applied. This method is most useful for engineering applications of soil mechanics. The dynamic loading and unloading in a fraction of a



Applied stress, log scale

Figure 5. Diagrammatic description of the soil bulk density or void ratio response to uniaxial stress (the solid line traces the compression response; the dashed line helps define the virgin compression line; the secondary compression curve and where it meets the virgin compression line depends on historical stress applied).

second in the Proctor test appears similar to that occurring during the passage of a wheel, but the method has not proven useful in analyzing and interpreting traction traffic (Hadas et al., 1988). Soil response to static loading can be measured in a consolidometer or triaxial cell, or merely a uniaxial stress applied to a soil in a confined container (Bradford and Gupta, 1986). The loading rate is so slow that it may be considered static. These static load tests are used to derive the compression index, which is identified in figure 1 and defined as the change in bulk density per unit of applied uniaxial stress along the virgin compression line (see fig. 5). These laboratory tests can be used to predict the depth of soil strain due to such factors as tire width and axle load (Swan et al., 1987). However, predictions from these tests (Warkentin, 1984) are based upon homogeneous soil and often fail when there are distinct soil layers. The compression index of figure 5 is sensitive to density of aggregates, clay content, and organic matter content; the density of aggregates changes the secondary compression line. When water content is changed the compression index does not change but the virgin compression line translates down (to a larger bulk density) as the water content is increased (Gupta and Larson, 1982).

Strain Gauge Studies

Measurements of bulk density or load on a penetrometer cone used after compaction has occurred in the field can detect traffic compaction, depth of tillage tool penetration, and a tillage tool pan, but are less sensitive in detecting the maximum depth of traffic induced compaction. Strain gauges are now being used in field studies to directly measure strain at various depths under various configurations of axle load, contact pressure, rutting, ground speed, and wheels or tracks (Kinney et al., 1992) because they record the displacement as it happens.

Strain curves in figures 6 and 7 show the results of two such tests. Strain gauges 140 mm long were

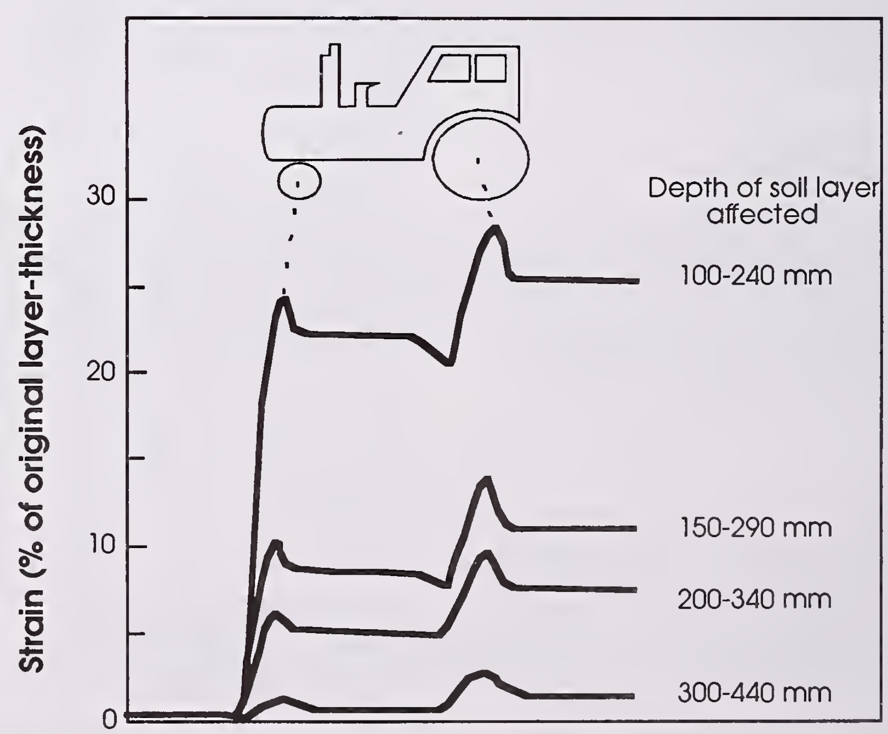


Figure 6. Strain produced by a medium-sized, rubber-tired tractor (without drawbar load) during travel on the soil surface (after Kinney et al., 1992).

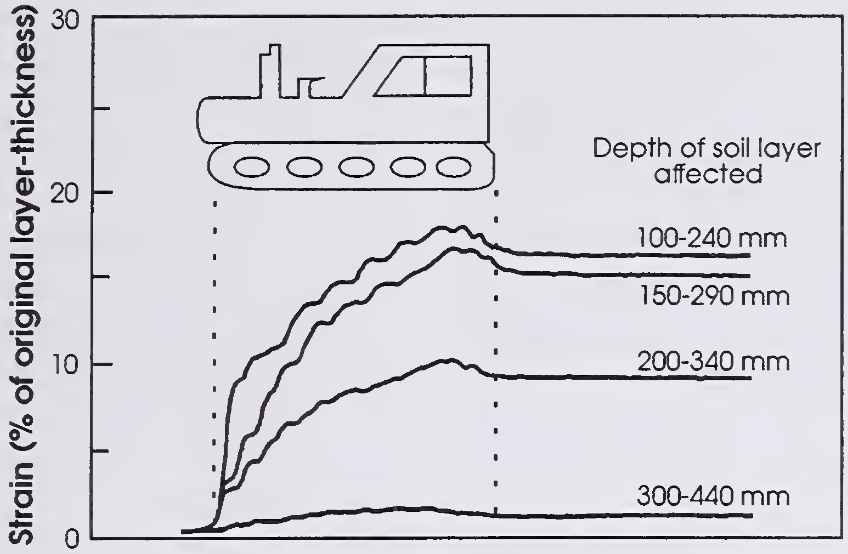


Figure 7. Strain produced by a crawler tractor (without drawbar load) during travel on the soil surface (after Kinney et al., 1992).

placed in the soil so that the top of a gauge was 100, 150, 200, and 300 mm below the soil surface, and the bottom of the gauge was anchored at 240, 290, 340, and 440 mm, respectively, below the surface. Strain was measured by the movement of the top of the gauge as a front and rear tractor tire (fig 6) or a track (fig. 7) passed over the gauge. A strain of 25 percent represents a 35 mm reduction in length of the soil layer between the upper and lower bounds of the strain gauge. An elastic rebound of the soil occurred after the passage of both the front and rear tire (or of a track), but the strain curves also verify that traction traffic can produce permanent strain below the level of the plow pan — an old plow pan was noted in this study at 300 mm. These levels of strain are conservative in that the tractors were not drawbar loaded. Strain curves in figures 6 and 7 clearly verify that a wheel tractor produces more compaction at shallow (100 to 240 mm) depths because of contact pressure, and that strain at 300 to 440 mm is nearly the same for both traction devices because the axle load is about the same even though the contact pressures are greatly different (Kinney et al., 1992).

Guidelines for Field Diagnosis

Cone penetrometers can be used for a preliminary survey to locate suspected compacted areas and layers. Areas of a nursery where problems such as poor drainage, poor seedling performance, or disease have been noted should definitely be examined for compacted layers. As was discussed in figure 2, a continuous record of load on the penetrometer cone must be made beyond the depth where no compaction is expected. Bradford (1986) suggests an initial 50 to 60 cm horizontal spacing of penetrations with a later fill-in should large differences be experienced between successive penetrations. He also describes two types of penetromters, the "Corps of Engineers" type for vertical penetrations and a pocket penetrometer for examining compacted layers by horizontal penetrations along the vertical wall of a soil pit. One cannot over emphasize the need to carefully log prior field operations with some estimate of the paths made by tractors and equipment — this should be done before extensive penetrometer use. When compacted layers are confirmed, bulk density cores can be used to develop a more accurate assessment of the depth, thickness, and density of these layers. As was pointed out earlier, smaller cores are more accurate in locating and characterizing thin compacted layers common in cultivated areas. At least 18 cores should be taken through the profile to at least 15 cm past the deepest suspected compaction (see fig. 4). When horizontal variation in the compacted layer(s) is suspected a set of soil cores is needed for each vertical variation. Further assessment of these compacted layers, such as porosity measurements, may be required to determine if they are adversely affecting rooting and movements of water and air.

ORGANIC MATTER — SOIL COMPACTION INTERACTIONS

Significance

Organic matter maintenance is a primary concern for continued seedling production in bareroot nurseries (Davey, 1984). Eighty-six percent of managers of bareroot nurseries surveyed for the *Forest Nursery Manual* (Duryea and Landis, 1984; Davey, 1984) were concerned that organic matter levels were too low. Of the five most serious problems identified by the managers,

compaction and organic matter maintenance each were included in 62 percent of the lists (Warkentin, 1984); inadequate drainage was included in 43 percent of the lists.

There were frequent comments about the need for more organic matter to control compaction and improve drainage. The relationship among these three concerns has not received the attention that it deserves. There are many observations of soil organic matter content changes in response to organic additions in the agronomic and bareroot nursery literature, but relationships between additions of soil organic matter and the resistance of amended soil to compactive forces are difficult to analyze and apply to soil management plans. There is a need for a systematic and theoretical approach to organic matter interactions with soil structure. Because organic matter also serves as a food reserve for biological activity there can be long-term soil structural changes.

Mechanisms

Soane (1990) reviewed organic matter interactions with compaction of soils especially in agronomic situations, although he recognized that horticultural enterprises are naturally concerned because of their larger additions of organic materials. There are six mechanisms by which organic matter may influence the compression and compactability of soil (Soane, 1990): 1) bonding forces between particles mostly within aggregates, 2) elasticity associated with organic materials lodged among aggregates, 3) dilution effect caused by the lower bulk and particle density of organic materials compared to mineral soil, 4) fungal and root filaments to bind aggregates together, 5) electrical charge effects on clays, and 6) surface coating to change friction between aggregates.

Effects

The effect of organic matter on the tolerance of aggregate structure to compaction is typified by a study (O'Sullivan, 1992) where previous cultural practices had resulted in a one percent increase in soil organic matter (long-term avoidance of moldboard plowing) in one area compared to another area (subjected to continuous moldboard plowing) of the same soil types. As more stress or load was applied (as in fig. 5), soils with higher organic matter had lesser decreases in specific volume (ratio of total to solid volume) and lesser increases in dry strength (resistance to crushing forces) compared to soils with lower organic matter. This relationship held over a range of soil moisture contents. Both soils showed greater specific volume decreases and dry strength increases under a given load or stress as soil moisture increased; however, soils with higher organic matter contents were more tolerant of compaction because of resultant changes in soil aggregate structure that reduced the dry strength and specific volume responses to applied stress.

Some other ways to evaluate compaction effects on intra-aggregate structure depend on the increase of cohesion upon drying, at which point individual aggregates are crushed to measure their tensile strength (Boyd et al., 1983; Dexter and Kroesbergen, 1985). Bonding forces inside individual aggregates can also be studied when wet (Kemper and Rosenau, 1986).

Before organic residues undergo extensive decomposition they can reduce compaction due to elasticity or rebound. Rebound is measured as a relaxation ratio (fig. 8), which is the bulk density of the test material under a stress divided by the bulk density after the stress is removed. When crop residues or organic additions are incorporated into soil, nearly all of the material is clustered and packed between aggregates (Staricka et al. 1991), where relaxation effects can preclude or mitigate compaction. Undecayed and partially decayed straw both have a relaxation ratio much larger than non-amended soil, especially at an applied stress of

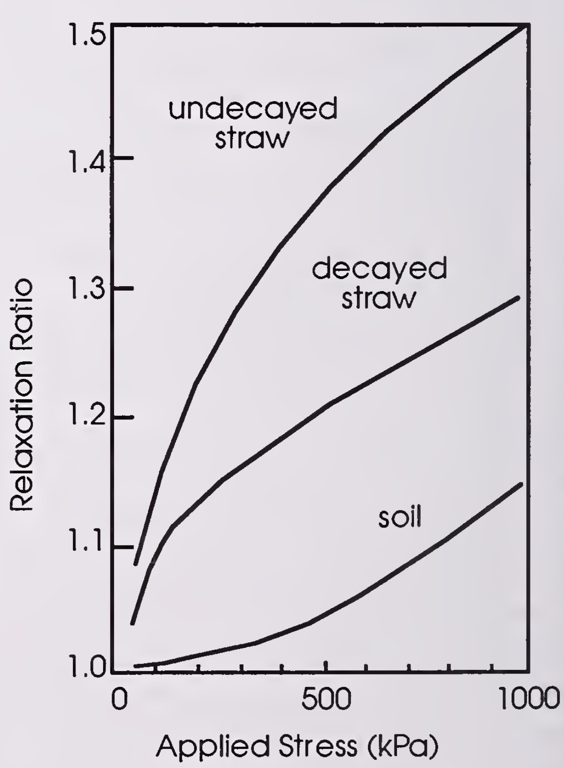


Figure 8. Relaxation ratio (elasticity) of soil compared to undecayed and decayed wheat straw (after Guerif, 1979).

300 kPa or less (fig. 8). Stresses applied in the field are usually in the 100 to 200 kPa range. This effect does not show up in the compression index as determined in figure 5, but instead the virgin compression line translates to a lower bulk density when organic additions are made (Guerif, 1979; Gupta et al., 1987).

The lodging of long-chain molecules produced by decomposition of organic matter stabilizes soil aggregates and, therefore, maintains good soil structure. Interestingly, the rupture and compressive forces associated with tillage actions are one means by which residue, as it decomposes into long-chain molecules, are lodged inside aggregates (Dexter, 1988; Staricka et al., 1992). Plant rooting can also place these molecules inside aggregates (Oades, 1993).

Incorporation of residues also leads to lower bulk density and greater water retention of soil, because organic materials have a lower particle density than soil materials. Organic materials are often clustered, whereupon their lower bulk density causes bulking of the soil. Soil volumes as small as 5 cm^3 had a lower bulk density as the weight of oats residue was increased in the soil volume (Staricka et al., 1991). This bulk density change was more than expected when taking into account the different particle densities of the oat straw and the soil, thus, a looser packing of the organic materials. Because cereal straws retain more water per unit mass at a given suction, water retention of soil with added straw was greater than with soil alone on a unit mass basis (Myrold et al., 1981).

SOIL ECOLOGICAL IMPLICATIONS

Compaction Effects on Root Function and Stress

Overall development of seedling roots may be influenced significantly by soil strength and compaction, soil temperature, and toxic concentrations of aluminum, salts, pesticides, and plant toxin (Russell, 1977; Asady et al., 1985). Seldom is the soil environment optimal for root growth under field conditions; stresses may result from water excess or deficiency, oxygen deficiency, mechanical resistance to root growth, sub or supra-optimal soil temperature, nutrient deficiency or imbalance, and pathogen or insect damage. Soil compaction can aggravate the effects of each of these potential abiotic and biotic stresses.

Compaction Effects on Root Pathogens and Disease Development

Interactions between a seedling root and soilborne pathogens are seldom predictable based upon each organism's separate response to aeration, penetration, and moisture stress. All of these stresses interact directly or indirectly with compaction. Such an interaction was documented (Miller and Burke, 1975) in a special root chamber in which bean roots were grown in a soil layered to simulate a compacted plowpan; soil water potential was held at -20 kPa (or -0.2 bars). In fumigated soil a 3-day treatment with reduced oxygen had little effect on plant growth 4 weeks later, but in soil infested with a root pathogen (*Fusarium* f.sp. *phaseoli*) there were permanent reductions in subsequent shoot and root growth. These responses intensified as the oxygen level was reduced (i.e. poorer aeration) during treatment. The ability of roots to penetrate the compacted layer was reduced by the *Fusarium* and essentially eliminated with the combination of low oxygen and the pathogen.

Compaction from both tillage implements and traffic can influence the survival and distribution of pathogen inoculum in soil. A plowpan was found at 20 cm depth in both wheat and pea fields (Kraft and Allmaras, 1985). These compacted pans were earlier shown to influence the severity and extent of pea root disease caused by *Pythium ultimum* and *Fusarium solani* f. sp. *pisi*. *Pythium* was characteristically found in the upper 20 cm of soil and was absent below the plow layer. The excessively wet plow layer in winter and spring favored *Pythium ultimum* in both its saprophytic and pathogenic modes. The *Fusarium* propagules were found throughout the upper 60 cm of soil, but their frequency was always low in the tillage pan just under the plow layer. The sparsity of fungus propagules in the tillage pan and their presence below it are related to the impaired drainage from compaction in the compacted layer and the saprophytic survival of *Fusarium solani* under dry soil conditions. However, in fields not cropped to peas for over 5 years, *Fusarium* was not detected in the plow layer, but was always recovered below it. Thus, the environmental optima for long-term survival of

the *Fusarium* pathogen occurred in the relatively dry subsoil.

Excessive soil compaction affects the rate and distribution of root growth, and thus affects the chances of successful host - pathogen contact and the dynamics of root-pathogen interactions. For example poor aeration or axial constraints on root development (such as mechanical resistance) may reduce the rate of root tip advance by as much as 75 percent and may also induce formation of laterals much closer to the root tip. The result is a more compacted and stressed root system. Exudates produced by elongating and/or stressed roots stimulate dormant fungal pathogen structures (e.g. chlamydospores, microsclerotia) to germinate and grow. The overall result is that soilborne pathogens in compacted soils are more likely to intercept young lateral root and obtain sufficient nutrients to infect that root. This may not be as important a factor in *Fusarium* root diseases, however, because *Fusarium* spp. usually exist largely as colonies growing epiphytically on the root surface.

MANAGEMENT IMPLICATIONS AND GUIDELINES

While soil compaction is a simple operation, i.e., a reduction in volume of a given mass of soil, it is a complex and involved process that challenges both the best nursery managers and the most capable agricultural scientists. Soil compaction involves interrelationships between most of the physical, chemical, and biological properties of soil as well as environmental factors such as climate, weather, tillage and agronomic treatments, and crop use. In turn, the state of compaction of the soil is largely responsible for soil water, air and temperature conditions and subsequently affects seed germination, seedling emergence, root growth, pathogen problems, and most other phases of seedling growth and production.

Knowledge of the processes by which the state of compaction may be modified and controlled, as well as a means of measuring soil compaction, is therefore essential for effective, sustainable nursery production. The selection and management of tillage equipment and cropping systems in nurseries should be directed at producing the optimum state of compaction at appropriate depths in the soil for the crop production cycle. The following guidelines are suggested as a basis for assessing soil compaction and developing practices to prevent or ameliorate soil compaction, and should be considered when developing nursery soil management plans (see Boyer, 1993, for an example of a nursery soil management plan.)

Locating and Mapping Soil Compaction

A systematic survey of the nursery for compacted soil layers is an essential first step in dealing with compaction problems. Ideally, this would be included as a part of an intensive soil survey to develop an accurate soil map during the establishment of new nursery fields. The fields should be checked to determine the depth and intensity (bulk density) of compaction layers formed by equipment traffic during grading and leveling operations (Thompson, 1984). However, even where these operations were not done, prior land use may have formed serious compaction layers, or naturally formed impeding layers may be present in the root zone due to the erosion of surface layers. Some soils also have naturally formed clay pans or duripans. The presence of these natural pans can often be inferred from soil survey maps, but county soil survey maps are not accurate enough to delineate soil boundaries or pan depth and intensity in nurseries. A soil survey on a 100- to 200- foot square grid to accurately establish soil boundaries is recommended.

As mentioned earlier, areas with poor drainage, poor seedling performance, or repeated disease problems should be examined in production fields for soil compaction. A cone penetrometer can be used to initially determine the extent or area of a pan already suspected. However, care must be taken to insure that differences in soil water contents do not confound soil penetration resistance measurements. For an initial assessment, a series of vertical penetrometer measurements taken in the interior of the beds (not on the tractor paths) consisting of one reading every 2 to 4 feet (depending on the size of the area being surveyed) should suffice. These measurements should extend beyond the suspected area of the pan in order to obtain a comparison with unaffected soil. An alternative using a pocket penetrometer involves excavating a series of soil pits

across the same area range and taking readings along the exposed soil face. Care must be taken to identify soil type boundaries in making these measurements, since different soil types will have different soil penetration resistance properties. Also, penetrometers may not always detect thin compacted layers that can impede air and water movement. For that reason, bulk density core samplings should be considered even when no compacted layers are detected with a penetrometer. Smaller cores are more effective in locating thin compacted layers, but are much more time-consuming than penetrometer measurements. Sampling recommendations for bulk density cores were discussed previously.

Ameliorating Initial Compaction Problems

If a natural or induced pan is detected during the initial survey, subsoiling should be done and no subsequent traffic should occur on the soil prior to preplanting tillage. However, this subsoiling should only be done in situations where the subsoil does not have good macroporosity (Taylor and Brar, 1991; Voorhees, 1992). Soil surveys and soil taxonomic descriptions should indicate when there is macroporosity due to bioactivity and soil cracks. Whenever possible, controlled traffic lanes should be used for this operation. Permanent tractor paths (as discussed below) could be located at the time of this operation if possible.

Reducing and Ameliorating Compaction Due To Nursery Operations

Moldboard plowing and rototilling are likely to form tillage pans. These operations should be carried out so that only surface traffic occurs, i.e., tractor wheels should not travel in the furrow when moldboard plowing. This will avoid excessive compaction below the tillage layer. Bulk density measurements within the rooting zone (see fig. 3 and 4) are useful to assure that no compacted layers remain after subsoiling.

Rototilling also causes fragmentation of soil aggregates; aggregates with good internal strength are a means to prevent soil compaction and related problems of poor soil drainage. Adjust travel and rotation speed of rotary tillers so that beds are not overtilled — finely pulverized soil is only needed in the layer (or better yet the zone) where seeds will be sown.

As discussed earlier, soil organic matter content is an important factor in the ability of soil to resist compaction. Maintaining soil organic matter through green manure crops or direct application of material such as peat or sawdust (maybe both when possible) is therefore important for improving both chemical and physical soil properties.

Whenever possible, incorporate crop residue or organic material by shallow disking or rototilling followed by a chisel operation. Disks and rototillers are very efficient in incorporating residue, but leave a tillage pan that is likely to limit internal water drainage. Shank mounted tools such as chisel plows can help eliminate shallow tillage pans, but are not efficient residue incorporation tools. Tillage tools should be kept sharp and properly set for maximum performance. Dull, or improperly adjusted tools cause undue compaction.

Tractor paths should be relocated as accurately as possible in each production cycle. Compaction from repeated wheel traffic often extends below tillage depth (see chisel tillage in fig. 4), and can be difficult to ameliorate even with subsoiling. Compaction at this depth can impede water flow, perch water tables, reduce aeration even upward into the Ap layer. Moreover, compacted soil in traffic paths is often not completely ameliorated by fallowing and normal tillage operations. It is often possible to observe old tractor paths in beds because of the poor growth of seedlings in these areas. For that reason, the location of tractor paths should be considered permanent from crop to crop.

Lifters, especially those with a shaking action, can cause a compacted layer. This is especially true since they often must be used in periods of high soil moisture. This compacted layer should be ameliorated without delay; poor drainage caused by this layer may encourage saprophytic survival of water mold type pathogens such as *Pythium* and *Phytophtora* species.

Finally, there may be options in scheduling machinery use in relation to rain or irrigation. As a general rule, the potential for soil compaction increases with soil water content, with maximum

compaction occurring at or slightly below field capacity. Field operations should be conducted at the lowest possible soil moisture level for machine operation. It is well known that higher amounts of soil organic matter will expand this soil moisture window.

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1993 Missoula Technology and Development Center Nursery and Reforestation Projects[1]

Richard J. Karsky[2]

Abstract – The Missoula Technology and Development Center has provided improved equipment, techniques, and materials for Forest Service Nurseries and for Reforestation projects, for more than 20 years. The Center's work has improved efficiency and safety throughout the Forest Service. Our current work is summarized in this paper.

NURSERY TECHNICAL SERVICES

This continuing project allows MTDC to provide technical services to Forest Services nurseries and to respond to requests from State and Private personnel. New applicable technology is continually monitored under this project and Center personnel disseminate this information by presenting papers at professional meetings and symposiums. MTDC also answers inquiries from field personnel, does on-site visits to various Forest Service nurseries and provides drawings and publications on request.

Recent project accomplishments include:

1. Fabrication drawings for a new Mulch Spreader designed and built by the J. Herbert Stone Nursery.
2. Completions with the help of Tom Landis, Brenda Holland, and Ben Lowman, of the Bare Root Nursery Catalog.

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

[2] *Project Leader*

MACHINE VISION

Tree seedlings are grown in Forest Service Nurseries based on specifications tailored to specific Forest and District needs. After lifting, seedlings are delivered to packing sheds for grading and packing. Each nursery has developed its own quality control standards for the seedlings that they deliver to the field units for planting. The current quality control method is by having checkers sample graded seedlings and monitor the graders on the packing belt.

The machine vision equipment is otherwise known as a quality control module. The purpose of the equipment, initially, is do quality control inspection of seedlings that have been processed in the packing sheds.

This work is being done under contract with Dr. Glen Kranzler and Mike Rigney of Oklahoma State University. The object of the project was to develop a PC computer based system that would measure root mass, stem mass, measure length, caliper, sturdiness ratio, (which is a ratio of the length divided by the caliper), and other miscellaneous properties. Because it provides a silhouette image to the camera, it cannot detect surface characteristics such as discoloration. With this information the nursery can evaluate if the seedlings are graded to specification and also determine the quality of seedlings in a seed lot.

The system will have an accuracy of one-tenth of an inch in measuring length and one-tenth of a millimeter in measuring caliper. The speed of the machine inspection rate is a function of the seedling length because the camera does a line scan of the seedling image. The machine will have an inspection rate of about 20 seedlings per second of 1-0 stock and about 10 seedlings per second of 2-0 stock.

The real challenge of the overall system will be the material handling of the seedling into and away from the machine vision system. It is estimated that it would take about 5 people to feed the machine vision belt at the 10 to 20 seedlings per second rate. An early working demonstration of the machine vision "Quality Control Nodule" is scheduled for next January and appears to be on schedule.

Figure 1 – MTDC Seedling Counter

SEEDLING COUNTER

A machine has been developed by NTDC to aid in taking inventory of seedlings that are being grown in nursery beds. The machine passes over a row of seedlings and a scanning device board computer counts the number of seedlings in that row.

Nine seedling counters have been delivered to the Federal nurseries that ordered them. New post processing software that incorporates pull-down menus will make it easier to evaluate the results obtained by the counter.

ROOT PRUNER

Existing root pruning methods used by nurseries in the packing shed were investigated. The most common method currently being used to prune roots to field specifications are modified and operated paper cutters. A number of different cutters were tried.

Some concepts for an improved root pruner were developed. We started with rotating cutters, hedge trimmers, and pruning shears. The latest version uses a guillotine type blade operated by an air cylinder. This version currently does not have the capacity to replace all that paper cutters now present at the end of the packing belt. A cylinder capable of higher cutting forces is being added to the machine as well as more loading positions to increase the machine's capacity. Further testing is scheduled for the fall of 1993.

SEED SEPARATOR

Forest Service nurseries are currently reporting difficulties in obtaining separation of pitch from tree seed. This is especially true with white pine and western larch seed. Nany seed separation devices are used in the agricultural area that are not presently being used in tree seed cleaning operations. This project started in FY 1992. Initial testing and consultation with Bob Karfault, Director of the National Tree Seed Laboratory in Macon, Georgia, revealed that a vibratory separator was the most promising for separating pitch from seed. NTDC has purchased a small vibratory separator to do further tests and field demonstrations in. Commercial products are available for removing pitch from seed, but a technique or learning curve needs to be developed to find the ideal settings of the vibratory shakers. Four commercial machines were tested and one shows promise.

SMART TOOLBAR

Nursery equipment operators have experienced problems in maintaining toolbar height at a consistent level above the seedbed while doing various cultural operations. This capability is essential for such tasks as root wrenching, root culturing, and top pruning. With current technology, it is possible to design a system that can automatically sense toolbar height above the seedbed and simultaneously adjust a toolbar to maintain whatever level is desired. Essentially, this project will test various distance sensing devices, determine the most applicable device, and design a toolbar system for automatic height control. This idea originated at the J. Herbert Stone Nursery and NTDC will be working with them on this project. m e project began in

October 1991. Testing of ultrasonic measuring devices to determine distance is underway.

Sensor

The original ultrasonic sensor to determine vertical height came with a custom program that was specified by NTDC that averages a number of readings from the ultrasonic sensor. This should reduce and possibly eliminate false readings of ground surface echoed by the growing vegetation. Test show that the sensor still confuses vegetation with the gorund surfaces. m ree other manufacturer's sensors will be evaluated in the near future.

Hitch

A hitch that maintains lateral alignment has been obtained from H & R Manufacturing Inc. This "Navigator" should provide lateral alignment of the 3-point hitch. The attachment will be modified to incorporate a height adjustable plate, which will then be controlled by the height sensor discussed above.

HARDWOODS CUTTINGS PLANTER

A planter was developed by the PFRA Shelter Centre, at Indian Head, Saskatchewan, Canada, that would plant cuttings from hardwood whips. These whips would be cut into 6- to 8-inch lengths with 3/8- to 3/4-inch diameters. These cuttings would then be dropped into a chute or guide, picked up by a pair of rubber-coated rollers, and propelled into a furrow that was just opened ahead of this device. The cutting would then be pushed the remaining distance into the ground by a wheel immediately following the planting device that also packs the dirt around the cutting.

The Lincoln-Oakes Nursery, Bismarck, North Dakota, looked at the Saskatchewan cuttings planter and decide that it would work for their applications. They built a 4-row unit and operated it at their nursery. After their field experience more improvments were made and incorporated into their planter and into a set of drawings that they provided to MTDC.

This spring a 3-row unit was built by MTDC for the Bessey Nursery located at Halsey, Nebraska. This planter has all the latest changes from the Lincoln-Oakes Planter along with other suggested improvements that they recommended for future versions. m e machine was used for this spring's planting. Lincoln-Oakes estimated that the production rate of the cuttings planter would be about 125 cuttings per row per minute under ideal conditions. The spacing of the cuttings are about 8 per foot row.

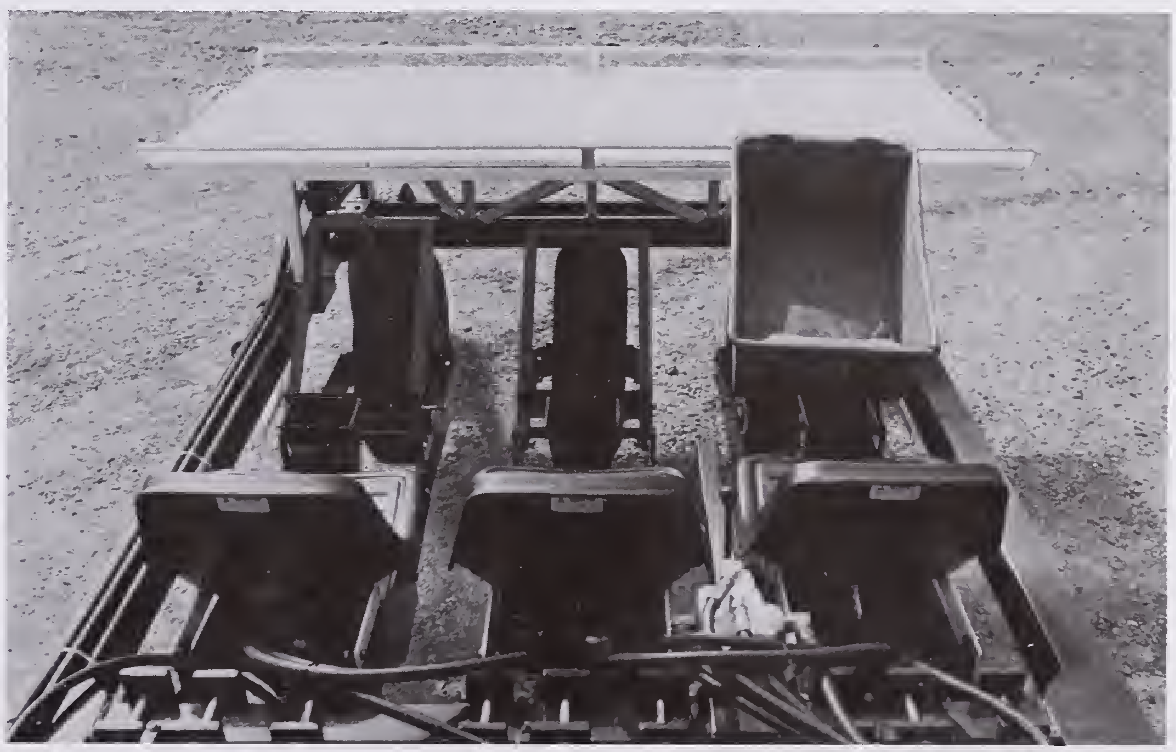

Figure 2 – Hardwoods Cutting Planter: three-row cuttings planter for planting six-eight inch long hardwood cuttings in a nursery bed

SCARIFICATION FOR NATURAL REGENERATION OF HARDWOODS

Natural regeneration of White Birch and other hardwoods is enhanced in shelterwoods and partial cuts if some site preparation or soil disturbance can be accomplished without damage to the residual stands. This dictated a need for some smaller more maneuverable tools and equipment to perform this task. MTDC has produced some small anchor chain implements that can be pulled through these stands with small crawlers or skidders to provide the desired scarification. The original blade of a small crawler can be replaced with a scaled down version of the "Salmon Blade" to perform the

desired scarification and maneuver around the standing trees. The Salmon Blade produces more scarification than the chains. Either implement can be used in areas with a large amounts of slash and debris.

STEEP SLOPE SITE PREPARATION EQUIPMENT

The current trend is to leave more material on the ground after logging for soil protection, wildlife habitat, and seedling protection. Leaving heavy amounts of slash and logging debris on the ground greatly complicates site preparation for natural and atrificial regeneration, especially if steep slopes are involved. The guidance group for this project determined what desired conditions should be present on the site for regeneration, and with that criteria what equipment would be available to do that job, with the emphasis on steep slopes.

A literature search was done to see what equipment would be available to operate on the various slopes. Although some of the machines were not currently used for site preparation work, only minor modifications or additions would be required to make them suitable for site preparation on steep slopes.

A report was prepared, *Site Preparation Equipment for Steep Slopes.* 9324-2804-MTDC, that discussess site preparation considerations and contains some of the commerical brochures of the equipment that would be suitable for work on steep slopes. The British Columbia Ministry of Forests also has published a Site Preparation Manual and has produced a videotape on excavators and related attachments that are being used for site preparation work on steep ground in British Columbia, Canada.

Figure 3 – Mulch for Seedlings: typical plastic mulch used to reduce vegetative competition for seedling

SEEDLING PROTECTION

MTDC has been working with the Southern Region Timber Managment to evaluate and improve, if possible, commerically available devices that can be used to protect seedlings from animal damage and promote growth. Europe has used these seedling protectors for years to improve survival of hardwood seedlings. Keith Windell, MTDC, and Dan Sims, R-8 Cooperative Forestry, recently traveled to England to observe first hand the long term effects of using tree shelters. For high value hardwoods it may have some potential. Various field test sites are in place and these protectors will be studied as to the durability of the shelters and how effective they are at protecting the seedlings.

MULCH FOR SEEDLINGS

Ground mulch is commonly used in the ornamental and landscape business to reduce vegetative competition and improve soil moisture around newly planted trees and shrubs. A preliminary investigation by Forest Service researchers indicate that ground mulch also can significantly improve survival and promote early growth of seedlings on National Forest lands. Data is being obtained on various types of mulch material and the techniques and equipment that is required to install

and maintain the material that are being evaluated.

POLLEN EQUIPMENT

There was a need for pollen gathering and application equipment for both research and also in the seed tree orchards. The method previously used was labor intensive and time consuming. Applicators have been made to apply pollen to individual flowers and also to mass apply pollen in the seed tree orchards. Pollen gathering equipment can harvest large quantities of pollen with a cyclone separator in short periods of time. Individual pollen collectors can also selectively gather pollen from individual trees if desired.

The current mass applicator uses air to deliver the pollen to the trees. This result in more drift and more pollen is required to insure that the tree is properly pollinated. A wet pollen applicator would have the potential to deliver more pollen to the tree with less drift and quantity required, but it is unknown how viable the pollen would be if it has been wetted and dried a number of times. Preliminary work is under way to develop a wet applicator.

PORTABLE POWER PLATFORM

A machine is desired to perform silvicultural operations such as thinning or creating planting spots that is small enough of to be maneuverable in forested areas without causing damage to residual trees. The machine would be somewhere in size between a hand operated machine and a small crawler tractor. The Iron Horse is a 25 HP tracked vehicle that can be used to skid small trees, with a special attachment can operate hydraulic equipment such as hydraulic thinning shears, provide planting spots, etc. In trials with the machine it appears that a larger unit would be desirable, but the current machine would be very versatile.

Figure 4 – Portable Power Platform: equipped with site preparation scarifier head

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2. *Mobile Tree Seedling Coolers.* Herzberg, Tech Tips, 9324-2302-MTDC
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4. *Mobile Tree Seedling Coolers*, Herzberg, Tree Planters Notes 44 (1): 16-18, 1993
5. *Progeny Seeder Operator's Manual*, Herzberg, 9224-2806-MTDC
6. *MTDC Nurseries Program*, Lowman, 9224-2818-MTDC
7. *Bareroot Nursery Equipment Catalog*, Lowman, 9224-2839-MTDC.
8. *Portable Power Platform*, Windell, Tech Tips, 9224-2301-MTDC

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13. *Site Preparation Equipment for Steep Slopes,* Karsky, 9324-2315-MTDC
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Single copies of publications and drawings are available from MTDC.

Bootheel Ag Water Quality and Precise Application Project[1]

Bill Holmes[2]

Abstract – In an effort to apply prescription farming techniques in the Missouri Bootheel, the Missouri Ag Water Quality and Precise Application Project, sponsored by the Bootheel Resource Conservation and Development (RC&D) Council, was funded and became operational in September of 1989. In general, the idea of prescription farming is to vary the application rates of inputs (pesticides, nutrients, irrigation, etc.) from point to point within a field, rather than using a single, average rate over the entire field. Applying inputs only where needed maximizes production efficiency and minimizes the possibility that over-applied chemicals (not utilized by crops) may contaminate ground or surface water.

PROGRESS TO DATE

This project was initially a three year project. One of the main goals was to determine whether there is enough variability within fields to warrant variable rate technology (VRT). We are maintaining a large database with information from lab analysis of soil samples from each field. Soil samples are taken on a 330 X 330 ft. grid and the results are loaded into the computer. The field is divided into zones for fertilizer application and the data stored in a digital map. Five fertilizer blends most optimum for the field will be spread by the computer driven spreader truck using this digital map. To date, we have grid sampled 10,000 acres and 9,000 acres have been processed for VRT application. Over 4000 acres have had fertilizer applied using a Soil Teq spreader truck.

It is clear that many of these fields will benefit from variable rate fertilizer application. It is not uncommon to see P levels range from <20 to >200 and K levels range from <100 to >400 in the same field. We believe the same benefits will be evident for VRT chemical application. In fact, much of the data generated in this project affecting fertility recommendations will be important factors when making chemical recommendations. Information about soil type, texture, organic matter, soil pH, and cation exchange capacity (CEC) will be key factors when dealing with many of the soil sensitive chemicals. Other factors will include matching the proper chemical with the pest that exists in various parts of the field. We hope to build on the knowledge and data gained in this project as we move into variable chemical application.

For the project we have incorporated Geographic Information System (GIS) methods capable of utilizing data from infrared photography, aerial photo base maps, and SCS soil survey maps to define differences in soil type, texture, and water holding capacity. This system utilizes several stand alone programs operating under a series of shell scripts. Many operations are integrated but some are not. Much efficiency is lost due to data translations required for data to pass from one program to another. This can be remedied by utilizing a true GIS relational data base environment. We are consulting with the Space Remote Sensing Center (SRSC)[3] located at the Stennis Space Center in Mississippi to develop this type system. We are in the process of converting all data from the project to this format.

Application rates have been recommended for each area of the fields using well established guidelines from the University of Missouri Columbia (UN MO). Recommendations for the project were made based on MU soil testing lab results. The fields were divided into five zone types having similar test values. The average test value for each zone was entered into the standard MU fertilizer recommendation program provided by Dr. Daryl D. Buchholz (MU).

The MU recommendation program will recommend enough fertilizer to grow the crop at the specified yield goal and build the

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

[2] *Oran, MO.*

[3] *Space Remote Sensing Center, Building 1103, Suite 118, Stennis Space Center, Mississippi 39529 (601/ 688-2S09)*

soil to an optimal level over an eight year period.

This site specific technology versus the conventional method represents a major shift of plant nutrients within the field. Areas with high test levels receive a lower application rate to avoid an excessive build up of nutrients. These are the parts of the field prone to cause environmental problems (i.e., leaching into ground water or runoff into surface water). The site specific concept also allows for an adequate amount of fertilizer to be applied to the lower testing parts of the field necessary for proper crop development. This will allow for the most efficient use of the plant nutrients that are applied and also the most efficient use of the other resources used to produce a crop.

Plant nutrients represent only a small part of the total resources involved in crop production. Other resources used, such as fossil fuels and raw materials for the production of farm machinery, also weigh heavily on the environment. If plant nutrients are allowed to fall below established optimum levels, the efficiency of all resources involved in crop production will drop. Field passes, fuel consumption, equipment wear, and manpower will not be reduced by lowering the fertility level of any field. Also, there is a point where production will not increase when nutrients are applied at excessive rates.

It is an important point to note that areas of the field that are at or being built to an optimum soil test level do not pose an environmental threat or hazard. In some cases it is possible to have a far worse environmental situation where some or all nutrients are not up to the optimum level for that area.

One such situation would be where some of the nutrients would be at high to excess levels and one or more other nutrients were at very low levels. In this case the crop would be starved from the lack of the deficient nutrients and would not be able to utilize as much of the nutrients that are in high or excess levels. The result would be more of the high level nutrients remaining in the soil subject to leaching or erosion into the ground or surface water. The key to wise and efficient nutrient management from both an environmental and an economic standpoint is nutrient balance at optimum agronomic levels.

Another environmental threat from soils being deficient in particular nutrients is poorer crop growth resulting in less crop residue left to protect the soil from erosion. With more erosion there will be more soil containing nutrients and pesticides entering the surface water.

So, what's all the talk about nutrient utilization, optimum agronomic levels, and poor crop growth? Let's get to the point. What most folks want to know is "If I use this technology how much can I reduce my fertilizer application this year".

The point is that success measured by pounds of nutrients not **applied to a field alone** is not a good assessment of this technology for reducing non-point source pollution or generating profits. In some fields we had a reduction of 35% and in others a 20% or 15% reduction. But in other fields we applied the same and in some cases even more than previous management had applied. So how can we say this site specific management is so great for the environment?

The main consideration is how much did we change the management of plant nutrients, pesticides, and all other inputs that will have a positive impact on non-point source pollution and my economic situation. On fields where we applied the same amount of total nutrients per field as the previous management, we redirected 30% to 40% of those nutrients from areas where nutrients were high or excessive to other parts of the field where nutrients were lower than the optimum level for good crop growing conditions. The fertilizer would have been applied to areas of the field that were already at high or excessive levels and prone to cause more environmental problems. On the other hand they were redirected to areas of the field that had low test levels and would pose no additional environmental problem and could enhance crop growth, better utilization of other nutrients, produce more crop residue to protect the soil, and add more profit for the producer.

In the SP53 [4] program, we calculated the difference between the previous rate the producer was applying and any point where the application was re-

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[4] *This was a pilot project sponsored by ASCS to implement Integrated Crop Management (ICM) practices. Five counties in the state were selected and twenty farms in each county were allowed to participate. A cost share of $7.50 per acre was paid to offset the cost to producers for participating.*

duced. This amount of fertilizer was either not **applied to the field** or redirected to other parts of the field where nutrients were lacking. Following is a list of the different nutrients and the percent they were either reduced or redirected for all fields.

N	4%
P	47%
K	40%
Z	85%
S	88%
Lime	38%
All Nutrients	26%

The P, K, and lime redistribution seem to be in a range that we would expect to be very typical for the area. The Z and S show being reduced or redirected by 85% - 88%. This seems to be a high number and indicates that the producer was over applying these nutrients for some reason and this situation is probably not typical of the region. The N on the other hand represents only a small change in management due to the way the recommendations were made. The N recommendation was varied based on the differences in organic matter only. Since the biggest factor affecting the N recommendation is the yield goal only small changes in N recommendations were made across the fields. In the fall of 1991 we collected about 400 hand harvested yield samples of corn using GPS to locate the sites. The sample sites were taken about the same spacing as the previous soil samples. In 1992 the Agricultural Engineering and USDA ARS group from MU collected continuous yield data with sensors and GPS equipment mounted on their plot combine. Stewart Burrell (MU) is currently analyzing this data for correlation with other field variables. Dr. Steve Borgelt with Agricultural Engineering at MU will be working with us in 1993 to mount a yield-o-meter provided by CLAAS and interface this unit to a GPS unit and moisture sensor. We hope to collect yield data on most of our crops this year. As more data about yields and yield potential is gathered and understood, a reduction and or redirection of N in the range of 25% will be a reasonable expectation.

EXISTING CHALLENGES

One of the big problems we face is managing the massive amounts of data that are generated by prescription farming. Being able to interpret the amount of data and make good agronomic and environmental recommendations is difficult. The collection and organization of data is time consuming and expensive. In the future, many types of data will be collected passively from sensors on farm equipment for automated input into decision aid systems. Also if data that is routinely collected by the normal activities of the Soil Conservation Service (SCS), Agriculture Stabilization and Conservation Service (ASCS), and other government agencies can be utilized by a compatible GIS, the cost will be reduced and the technology will be adopted by a larger number of producers for prescription farming purposes.

Now and in the future, SCS is and will be developing layers of data with the Geographic Resources Analysis Support System (GRASS), which is the GIS that will meet their needs. Some of this data will be invaluable for the purpose of prescription farming (if in a compatible format) and will reduce the cost of implementing prescription farming for the producer.

Another valuable source of information could be utilized from the ASCS activities. These include accurate field boundaries, crop history, and a universal method of naming (i.e., farm #, tract #, and field #) fields. Additional layers of data will need to be developed that may not be available from other sources, but will be critical for prescription farming recommendations.

ADOPTION CONSTRAINTS

How fast and to what degree this technology and these systems are utilized will depend upon several factors.

1. The ability to automate data collection.
2. The development of VRT equipment to apply prescriptions.
3. The user friendliness of these systems.
4. Cost of systems per unit served.
5. The extent of shared data by government agencies.
6. Economic factors affecting agriculture and the economy.
7. Technology transfer and education to agribusiness.

An Overview of the Role of Organic Amendments in Forest Nurseries[1]

Robin Rose[2]

INTRODUCTION

Organic amendments in agriculture have been with us for thousands of years so there is a great deal of comfort in knowing that it is the right thing to do. Tilled soils definitely require periodic, if not yearly, additions of organic matter in order to maintain tilth, fertility, and favorable water holding characteristics. There is no getting around the fact that organic matter degrades and must be renewed if the soil is to perform effectively as a growing medium.

Forest nurseries have many things in common with agricultural operations. However, there is one very large difference. The forest nursery manager is as interested in the root system of the crop as s/he is the top of the plant. Unlike the typical agricultural crop, the organic matter from the root system of a forest seedling crop is not left in the ground. Maintaining organic matter levels in a forest nursery soil can be a bit of problem depending on the local environment.

This paper is an overview of organic matter admendments in nurseries. It covers some of the general principles of how organic matter affects the physical, chemical and biological properties of soils, how organic matter is decomposed in soils, and the various uses for organic amendments. This is by no means an exhaustive review of the topic. There is an excellent review of this topic by Blumenthal and Boyer (1982), which is soon to be updated. Much of this overview is drawn from that paper.

SOIL PROPERTIES

Physical Properties. Tilth is highly associated with the amount of decomposed organic matter in soil. Nursery soils where organic amendments are made on a regular basis are usually easier to till, prepare beds, and lift seedlings. These same soils can also be less likely to compact under common working conditions.

Sandy soils seem to benefit the most in terms of physical properties where organic amendments are concerned. Some sandy soils tend to compact naturally due to their particle size distribution i.e. the grains of sand, silt, and clay fit so well together there is less pore space. Humus tends to retard this natural phenomenon because it gives the soil a more granular structure. Clay soils also benefit from humus as well.

Here is a list of some of the physical benefits of organic matter in nursery soils:

1) lowering of soil bulk density
2) less mechanical impedance
3) better soil aeration
4) greater soil water penetration with increases in soil structure
5) less soil erosion
6) increased water holding capacity

CHEMICAL PROPERTIES.

Organic matter is definitely a source of nutrients. Microbes - bacteria, fungi - decompose the organic matter into humus which eventually leads to a release of nutrients. There are several key

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[1] Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993

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concepts to understand about the release of nutrients from organic amendments. They are immobilization, mineralization, and the carbon to nitrogen (C/N) ratio. In the case of nitrogen immobilization microbes tie up nitrogen from the soil as they go about decomposing high carbon-low nitrogen organic sources. This phenomenon explains why seedlings turn yellow after fresh sawdust has been added to beds. The seedlings can not out compete the microbes for the N they need. Mineralization is where the microbes die after using up all of the available nitrogen and release the N tied up in their bodies. The C/N ratio is important because not all organic materials are the same and do not have the same C/N ratio. High C/N ratio materials require added fertilizer N if N immobilization by the microbes is to be avoided. Table 1 shows some C/N ratios for various plant materials.

Table 1. Carbon/nitrogen ratios of a few farm and forest products.(after Blumenthal and Boyer, 1982)

Organic Material	C/N Ratio, water-free basis
Alfalfa Hay	18:1
Meadow Hay	43:1
Wheat Straw	373:1
Oak Leaves, weathered	26:1
Douglas-fir bark (420 yrs old)	491:1
Peat Moss	58:1
Red Alder sawdust	134:1

The decomposition of organic matter depends on the following:

1) temperature
2) the level of oxygen in the soil
3) moisture
4) available minerals
5) the C/N ratio
6) the age of the organic matter
7) the physical composition of the organic matter i.e. lignin and cellulose contents.
8) the population dynamics of the microbial community i.e. species of microbes, population sizes.

These factors help explain why in wet cold soils the slow decomposition of organic amendments and why it is best to keep to already decomposed materials as additions in colder climates. In hotter climates where the growing season is longer and the microbial decompsition is rapid by comparison it is necessary to try to keep to large additions of organic matter. In the warmer climes it can be near impossible to increase the equilibrium level of organic matter with cover crops due to rapid decomposition .

Organic materials help the chemistry of the soil for one very important reason. Most materials have a very high cation exchange capacity (CEC), which means that they are able to bond with cations(NH4,K,Ca,Mg). So, by adding organic amendments to a low CEC soil like a loamy sand (CEC~2) it is possible to raise the CEC by adding an organic with a CEC~300. In the same vein, organic matter also buffers the soil against changes in pH.

BIOLOGICAL PROPERTIES

Organic matter is the source from which microbes get their energy. This includes both the friendly microorganisms like the mycorrhizal fungi and the *Tricoderma* spp as well as the unfriendly microorganisms like the *Fusarium* spp. One point that is constantly made in the literature is to the fact that it takes a wide mixture of species in the soil to maintain a healthy environment. There definitely needs to be a large and diverse community of friendly organisms to balance out the detrimental effects of such pathogens as *Pythium* spp, *Phytophora* spp, and *Fusarium* spp - just to name the major ones.

Mycorrhizal fungi benefit from organic amendments as evidenced by the common presence of roots with mycorrhizae on them buried inside a small chunk of bark or wood chip. The fungus decomposes the bark, providing nutrients for itself and the nursery seedling plus gaining carbohydrates from the seedling. I have yet to dig up seedlings in soil well supplied with organic amendments and not found many roots intertwining their way through the larger pieces of organic material.

There is far too much that we do not know about the role of specific organisims in soil and how those organisms positively impact seedling quality. This is made even more critical with the

legal requirements to move away from methyl-bromide soil sterilization. There is also much to be learned about how best to manage disease in soils without having to resort to sterilization.

MULCHES AND INCORPORATED AMENDMENTS

For the sake of simplicity both of these types of amendments will be discussed here because, in most cases, it is the same amendments being used in two different ways. Mulching amounts to putting a cover of a particular material over the newly sown seed bed in order to protect the seed from wind and water erosion, heat, and descication. On the other hand, incorporated amendments are usually disked into the soil in order to replenish the soil with organic matter. Incorporation is especially important in nursery soils to maintain or raise the organic matter equilibrium level.

There are a great many amendments that can be used. The common amendments for mulching are straw, sawdust, and bark. There are others like pine straw (needles), peat, hydromulch (paper sludge), paper mill and city waste sludges. Incorporated amendments tend to include sawdust, bark, and peat. Animal manures are also common, but acidic ("hot") manures like turkey and chicken need to be incorporated well enough in advance to avoid killing the seedlings. Sludges are also used, but they need to be thoroughly investigated prior to use. In fact, all organic amendments should be analyzed prior to use in a nursery since they may contain contaminants like pathogens or heavy metals. Green manures are often grown for incorporation, but it would seem that most green manure crops really do not alter the equilibrium level of organic matter. They can in some instances get the microbial populations so active that there is a net decrease in soil organic matter!

NITROGEN IMMOBILIZATION

It is an on-going issue as to how much nitrogen to add to the soil after adding an organic amendment to a soil. Usually, there is not much to be concerned about when mulching unless there is no other choice but to mulch with fresh wood chips or sawdust, then it may be necessary to add nitrogen. The more common problem is knowing how much nitrogen to add to a soil while incorporating any one of a number of organic amendments.

Table 2 shows a few examples of the amounts of nitrogen immobilized by microbes while decomposing some of the different sawdusts (Blumenthal and Boyer, 1982). If you were to take 1 ton of white pine sawdust and add it to an acre, the percent nitrogen immobilized after 160 days is .41 i.e. .41%. In order to prevent that potential immobilization from hurting the nitrogen uptake of the crop it is necessary to add 8.2 pounds of nitrogen per acre. The calculation is .0041 times 2000 pounds. Over 10 acres that is 82 pounds of nitrogen. That is not a lot of nitrogen and has the poten-

Table 2. Amount of nitrogen immobilized by micro-organisms decomposing sawdust of different softwoods and hardwoods. (modified from Blumenthal and Boyer, 1982)

Type of Sawdust	Percent Nitrogen immobilized after 160 days
Softwoods:	
Eastern Hemlock	.42
Douglas-fir	.30
White Pine	.41
Loblolly Pine	.60
Ponderosa Pine	.42
Hardwoods:	
White Oak	1.09
Yellow Popular	1.05
Black walnut	1.07

Source: Allison, 1965

tial to cause some problems in application trying to spread so small an amount over such a large area. However, given the amount of nitrogen put on nursery crops adding a little more fertilizer to the normal fertilizer schedule usually takes care of any problems. Of course, as the amounts of organic material increases where several tons may be going on per acre, it may be best to delay the sowing of any seedlings for a year and simply allow the soil and microbes to equilibrate.

Using low C/N ratio materials (<20), which has been known for years, is probably best. My preference is sawdust or bark that has been composted (left to sit in a pile somewhere on the nursery) for several years. This kind of material is ideal because it is not necessary to worry about immobilization and it can be used as a mulch and an incorporated amendment.

MEASURING ORGANIC MATTER

There are basically three different methods, which will not be gone into in any detail here. One of them uses perchloric acid, another uses potassium dichromate, and the other merely determines the loss on ignition in a muffle furnace. The first two have gone out of vogue due to safety hazards involved with them, even though they are considered the more accurate ways to measure organic matter by some. The latter method works very well, but can lead to errors with some soils. The suggestion here is to use the loss on ignition method and run enough samples over time to get a very good idea of where your soils are at in any give area. It is always adviseable to send in two samples that you know are the same but identified as different samples in order to check the accuracy of the lab. Knowing the organic matter percent to the nearst 1 percent is all that is required or necessary.

POSTSCRIPT

At this writing Don Boyer is planning to rewrite his very lengthy paper on organic amendments in nursery soils. Hopefully, it will be in-press in 1994.

LITERATURE CITED

Blumenthal, S.G. and D.E.Boyer. 1982. Organic amendments in forest nursery management in the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Administrative Report, October 1982, pp 73.

Overview of Green Manures/ Cover Crops[1]

J. F. Power [2]

Abstract – Frequently a cover crop or a green manure is utilized in nurseries for a number of reasons, such as to reduce soil erosion, provide ground cover and return organic matter to the soil, break up insect and disease cycles, add nitrogen to the soil, and for other reasons. There are many plant species to choose from, each with its own growth habits and requirements. In order to select the best species for a given soil and climate, growth period, and time of the year, one needs information on characteristics of various species. Results from greenhouse and field studies in Nebraska and North Dakota indicate that hairy vetch and soybean are generally well adapted cover or green manure crops for midwestern United States and can be grown at almost any time for any length of time desired. Hairy vetch can also be grown as a winter annual. Crimson clover is also a good winter cover crop for the southern part of the United States, but is not sufficiently winter hardy north of mid-Missouri/Kansas. For 45-75 days of early spring growth, field peas and faba beans are well adapted. For longer growing periods, perennials and biennials such as sweet clover, alfalfa, rose clover, and others grow well. For warm mid-summer plantings, species such as tinga pea, lespedeza, and cowpea should be considered.

INTRODUCTION

Cover crops provide ground cover and protect against soil erosion, immobilize residual soil nitrates and reduce nitrate leaching potential during non-crop periods, add nitrogen and organic matter to soils, stimulate soil microbial activity, improve infiltration and soil water relationships, break up disease, insect, and weed cycles, and have a number of other beneficial effects. Green manure crops likewise have many of these same effects, but impacts may be greater because they grow for a longer period than cover crops and provide greater biomass. If the cover crop/green manure is a legume, they have the added advantage of potentially adding more nitrogen to the soil plant system, thereby reducing need to add fertilizer nitrogen. Thus these crops may have a number of beneficial impacts (Power, 1987; Hargrove, 1991).

There are a number of crop species that could be used as cover/green manure crops. Also there are situations where use of such crops could be beneficial. Thus it is important that the growth characteristics of the species used match the soil, climate, and time period available for growth. Some species grow most rapidly at lower temperatures, others at higher temperatures. Also some do better than others under water stress. Some have rapid initial growth rates whereas others start slowly but do better later. The purpose of this paper is to present results from several experiments designed to measure relative growth rates and characteristics of a number of species. This information should help in selecting species suited to the local soil, climate, time of year, and length of time available for growth at the site under consideration. Results of three experiments are discussed. One was conducted in the greenhouse in which a number of species were grown at three different soil temperatures for varying lengths of time (up to 119 days). The second was a field experiment conducted on a Williams silt loam for two years at Mandan, North Dakota in which a number of species were planted at several dates during the summer, and sampled about every six weeks. The third experiment was a field experiment similar to that at Mandan but located at Lincoln, Nebraska. Information was collected on a number of growth characteristics in these experiments, but only information on dry matter production is presented here.

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[1] Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993

[2] J. F. Power is Research Leader, Soil and Water Conservation Research Unit, Agricultural Research Service, USDA at University of Nebraska, Lincoln NE.

Table 1 – Relative rate of growth (rank) of eight species studied at three soil temperatures and five sampling dates

Days of treatment	Soil temp. (°F)	Rank 1	2	3	4	5	6	7	8
35	50	FB†	SB	FP	HV	CC	SC	WCL	LD
	68	FB	SB	CC	SC	HV	FP	WCL	LD
	86	FB	SB	FP	HV	CC	SC	LD	WCL
56	50	FB	SB	HV	CC	FP	SC	WCL	LD
	68	FB	SB	CC	FP	WCL	SC	LD	HV
	86	SB	FB	LD	SC	WCL	CC	HV	FP
77	50	FB	WCL	HV	SC	CC	LD	FB	SB
	68	SB	SC	CC	LD	WCL	HV	FB	FP
	86	SB	LD	WCL	SC	HV	FB	CC	FP
98	50	WCL	CC	LD	HV	SC	SB	FB	FP
	68	SB	LD	CC	SC	WCL	FB	FP	HV
	86	SB	LD	WCL	FB	CC	FP	SC	HV
119	50	WCL	CC	HV	SB	FB	LD	FP	SC
	68	SB	LD	WCL	HV	FB	SC	CC	FP
	86	SB	LD	SC	WCL	HV	FB	CC	FP

† FB=faba bean; SB=soybean; FP=field pea; HV=hairy vetch; CC=crimson clover; SC=sweet clover; WCL=white clover; LD=lespedeza

RESULTS

Ranking of species in regard to their relative growth rates for the controlled temperature greenhouse experiment are presented in Table 1 (Zachariassen and Power, 1991). For the first 56 days after planting, growth was most rapid for faba bean and soybean at all soil temperatures. These were generally followed by field peas, hairy vetch, and crimson clover. Except at low soil temperatures, sweet clover and lespedeza also often were in the top four species. After about 77 days of growth, soybean was by far the fastest growing species except at the low soil temperature - soybean yields were usually at least double those of the next best species. Next best species were usually lespedeza followed by sweet clover and white clover. At the low (50°F) soil temperature, field pea, hairy vetch, and white clover were the top species with 77 days of growth. Generally field peas and faba beans were starting to mature after 77 days at the warmer temperatures, so they often gave relatively low yields for those situations. Likewise hairy vetch and crimson clover were approaching maturity and their growth rates were also slowing down.

In the field trials, the 50°F planting treatment was simulated by planting in the spring when soil temperatures are normally in the 50-60°F range. The 68°F treatment was simulated by planting in June, and the 86°F treatment by planting in July or August when maximum soil temperatures would occur. Samples of the vegetation produced since seeding were then taken periodically the remainder of the growing season.

Results from two years of field trials in North Dakota are given in Table 2 (Power, 1991). Results agreed well with those from the greenhouse experiment. For the May planting, only faba beans and field peas produced more than 1000 lb dry matter per acre by June 20. By July 12 field pea and subterranean clover were the

Table 2 – Aboveground dry weight (two-year average) of legume species † at several sampling dates following four planting dates, Mandan, North Dakota

Planting Date ‡	Sampling Date	HV †	SBCL	SB	FP	FB	LD	RCL	SWCL	BFT	ALF	LSD
		POUNDS PER ACRE										
May	*June 20*	360	380	460	1570	1390	§	§	190	§	140	160
	July 12	980	2060	880	3520	1380	520	260	880	330	1090	290
	Aug 1	1250	4490	1880	3730	1990	1300	710	1600	610	1530	340
	Sept 19	1500	2640	¶	¶	¶	2880	1460	2180	970	2080	280
June	*July 12*	290	190	610	690	930	§	§	90	§	90	100
	Aug 1	480	470	1310	1310	1470	300	130	530	§	250	140
	Sept 19	1930	1920	1040	¶	¶	2110	1390	1730	860	1580	200
July	*Sept 19*	220	440	1260	2160	1650	330	110	1130	§	600	190
Aug	*Sept 19*	220	§	§	540	630	§	§	§	§	§	200

† HV=hairy vetch; SBCL=subterranean clover; SB=soybean; FB=field pea; FB=faba bean; LD=lespedeza; RCL=red clover; SWCL=sweet clover; BFT=birdsfoot trefoil; ALF=alfalfa

‡ Planted between first and fifth day of month indicated

§ Insufficient growth for sampling

¶ Crop matured

best producers. It is interesting to note that in this environment, early spring seeding of soybean resulted in slow growth by this date. Likewise growth for lespedeza was slow. If allowed to grow until August 1 or September 19 (green manures), several species produced over 3000 lb dry matter per acre from the May planting. By the latter date, lespedeza did well.

For the June planting, highest yields by July 12 were for faba bean, followed by field pea. By August 1, these species plus soybean were the leading producers. If handled as a green manure and allowed to grow the entire season, lespedeza, hairy vetch, and subterranean clover were the best producers For the July and August plantings, hot dry weather at that time of the year often delayed emergence to the extent that there was insufficient growth to sample before frost in September. Again field pea and faba bean grew best for this short time period. In these trials, perennial species such as alfalfa and sweet clover generally exhibited slow initial growth, but moderate season-long growth.

Three year average dry weights for similar field trials at Lincoln, NE are given in Table 3. This was a warmer more humid climate than Mandan. However results are in general agreement with those from the two earlier studies (Table 1 and 2). For the early planting, dry weights by early July were again greatest for field peas (or Austrian winter pea spring planted), hairy vetch, and soybean. By August, dry weights for soybean were clearly much greater than for any other species, while those for hairy vetch were also much greater than the other species. This was generally still true by time of the fall frost; by fall, yields for crimson clover and sweet clover were in the 2000-3000 lb per acre range. For the mid-summer plantings, dry weights by fall were again much greater for soybean than for any other species. Hairy vetch and alfalfa were the only other species to produce over 1000 lb per acre by this time.

Mention should be made of several other species studied for only two years at Lincoln (data not given). As in the other trials, spring-planted faba bean grew as well as any other species the first 60-90 days after planting. Also again, lespedeza exhibited slow initial growth but rapid growth during the warm part of the season. Tinga pea also grew well at all planting dates, and cowpea at the midsummer plantings.

Table 3 – Average (3 yr) dry weight of cover crops at several planting and harvest periods, Lincoln, Nebraska.

Planting:	4/27 - 5/17		6/25 -7/15	
Harvest:	7/3-11	8/8-13	Fall†	Fall
	dry weight, lb per acre			
Soybean	1100	4010	5760	2110
Field pea/AWP‡	1660	1850	M§	840
Hairy vetch	1330	3210	3540	1570
Alfalfa	440	1440	1830	1430
Rye	740	1210	1060	940
White clover	300	780	1080	140
Sweet clover	850	1880	2250	630
Crimson clover	740	1620	2950	450
LSD0.05	170	510	610	210

† After frost ‡ Austrian winter pea § Matured 2 or more yrs by harvest

DISCUSSION

All three experiments gave similar results in that they showed that certain species were well adapted to one set of conditions whereas other species did best under other conditions. In general soybean and hairy vetch were two species that in most situations performed reasonably well. (However soybean may not be well suited to very early spring plantings). One does not generally think of soybean as a cover or green manure crop, but these results indicate that in many situations soybean was much superior to any other species. Likewise, in spite of the fact that there has been essentially no genetic development of the species, hairy vetch was also well adapted whenever used. Other research has shown that hairy vetch is best adapted to well-drained soils and is subject to loss of stand if kept in wet soil for extended periods. It is also the only legume cover crop that is sufficiently winter hardy for use as winter cover in the northern half of the United States.

Results from all experiments indicated that for short growing periods in the spring (45-75 days), large-seeded annual species such as field pea and faba bean and sometimes soybean are best suited as a cover crop. However for mid-summer plantings, such as after small grain harvest, species such as soybean, cowpea and tinga pea are also good candidates. If a longer period of growth is possible (over 75 days), species such as lespedeza and sweet clover often did well, in addition to soybean and hairy vetch. Thus it is apparent that one needs to carefully define the conditions under which a cover/green manure crop is to be grown in order to select the best species to use.

It needs to be pointed out that in these studies, generally only one variety of each species was evaluated. We have very little information on differences between varieties within a species, but we do know that there can be large differences. Much additional research is needed to evaluate these differences. Also there is considerable potential for varietal improvement through selection and breeding. As mentioned earlier, although hairy vetch is one of the most universally adapted species studied, there has been essentially no variety improvement work done on this species. The Madison variety is merely a selection made over 50 years ago from seed stock of unknown origin brought in by homesteaders in Nebraska. It appears that there might be a tremendous opportunity to develop this species further.

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The Use of Green Overwinter Mulch in the Illinois State Nursery Program[1]

Albert F. Stauder, III[2]

Abstract.— Spring oats are used in conjunction with hydromulch to provide a green overwinter mulch to the stratifying seed. Spring oats are used to protect the seed and seedbed from washing, and they provide insulation from cold winter temperatures. Because spring oats die in the winter, they eliminate the need for spring herbicide treatments. The Illinois nursery programs use the green overwinter mulch in the production of all species grown that are planted in the fall.

The Illinois Department of Conservation, Division of Forest Resources operates two nursery facilities - the Mason State Nursery near Topeka, Illinois, and the Union State Nursery near Jonesboro, Illinois. These nurseries have been in operation since the early 1930's, and the plant material at both facilities is used for planting on private and public property. Production at both nurseries consists of tree and shrub species for afforestation, reforestation, windbreak, and wildlife habitat projects. In addition, the Mason State Nursery produces seed and seedlings of prairie forbs and grasses for the establishment of prairie restorations.

Currently, nursery production averages approximately 4.5 million seedlings per year. Hardwood production comprises 54 percent of the total seedlings while conifers, native shrub species, and prairie forbs constitute 28, 11, and 7 percent, respectively, of the total production. Today both the Mason and Union Nurseries are involved in the production of over 130 plant species.

From the beginnings of plant nurseries, managers have used mulch to protect the newly planted seeds from sun, wind, and excessive rainfall. The mulch also serves to protect the seedbed from washing due to heavy rains. The mulch material is placed over the seed and should persist until seed germination is complete. Several different types of mulches are being used in the nursery industry; these include straw, sawdust, bark, wood chips, hydromulch, and synthetic materials.

Typically, most of our seed for the Illinois nursery program is sown into the seedbeds during the fall months. This provides the seed with a long, natural stratification period which insures rapid, consistent germination in the spring.

With the Illinois nursery program, we have chosen to use hydromulch as our standard seedbed covering. Currently we are using ground newsprint hydromulch. This material is easy to apply and persists throughout the winter stratification period. In addition, spring oats are added to the hydromulch. As the oats germinate and grow, they serve as a green overwinter mulch where they help to secure the hydromulch in place while providing additional protection and insulation to the seed.

METHODS

Hydromulch is added to water in the hydromulcher. Currently the nurseries use 250 pounds of hydromulch to 800 gallons of water. Approximately three pounds of spring oats are added to this mixture, and the slurry is then sprayed on top of the seedbed. Each tank covers approximately 800 linear feet of seedbed. Therefore roughly 3,200 pounds of hydromulch and 40 pounds of spring oats are applied per seedbed acre. The oats are trapped in the hydromulch and are applied very uniformly across the top of the seedbed; no problems have occurred due to the addition of oats to the hydromulch.

The oats will germinate in approximately ten days. Nor-

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

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mally the oats will grow approximately six to eight inches during the fall. The oats are now serving to hold the hydromulch in place, protecting the seedbed and providing insulation from cold temperatures to the stratifying seed (Figure 1). During the early winter the cold temperatures and repeated frosts kill the oats; however, they do persist throughout the winter to provide protection (Figure 2).

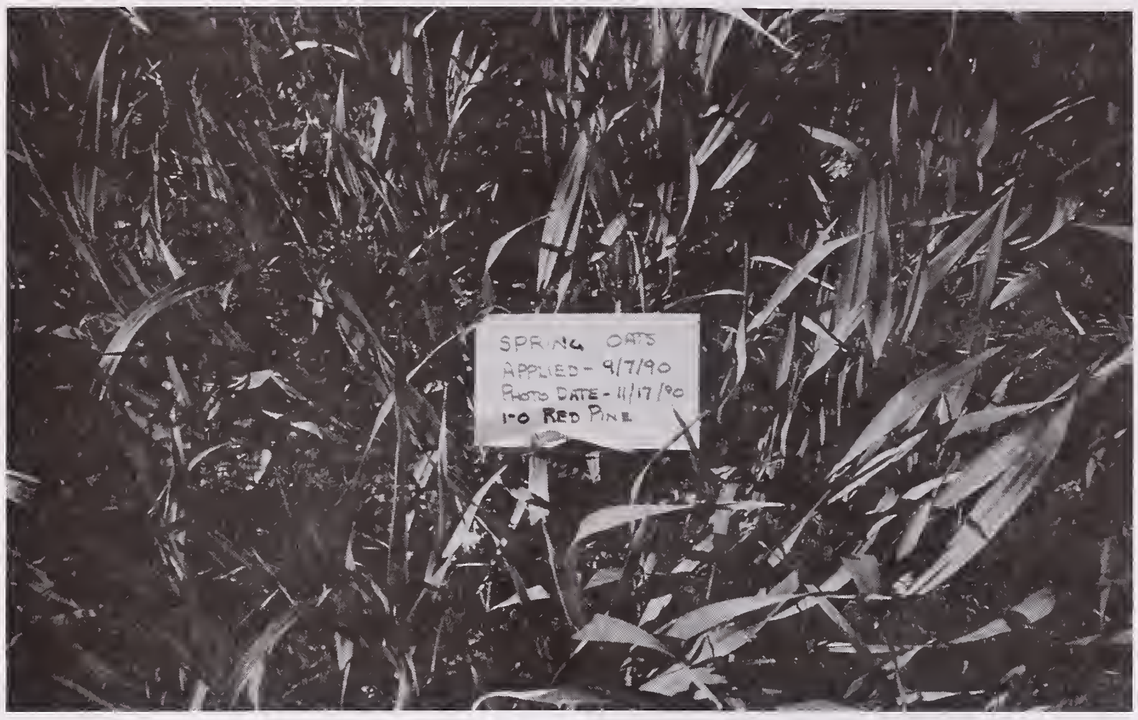

Figure 1. Green overwinter mulch two months after application.

Figure 2. Spring oats killed by winter temperatures and frost.

The application of the overwinter mulch is also used for the 1-0 red pine that is to be carried over for another growing season (Figure 3). The same application rates as that for newly planted seedbeds are used. The foremost objective here is to provide insulation from the cold temperature to the small seedlings.

CONCLUSIONS

We feel that the use of spring oats as a green overwinter mulch works well for the nursery operation. Advantages of using spring oats as an overwinter mulch are:

1. Secures the hydromulch in place
2. Protects the seed and seedbed from washing due to heavy rains
3. Provides insulation from cold temperatures
4. Dies in the winter to eliminate the need for early spring herbicide treatments.

The primary disadvantage of using this mulch program is that the oats require a fairly warm germination temperature. Therefore, oats may not work satisfactorily for late fall plantings.

The nurseries produce a wide variety of species with numerous seed sizes and germination rates. This described approach seems to work well for all of the seed we have grown thus far.

Figure 3. Mulch used to overwinter 1-0 red pine.

Use of Wheat as a Living Mulch to Replace Hydromulch for Fall Sown Seedbeds[1]

Jim Wichman[2]

Abstract – Wheat is used as a living mulch for fall sown seedbeds in place of hydromulch. Methods of sowing and management along with the advantages and disadvantages are discussed.

INTRODUCTION

Nurserymen of the Indiana Division of Forestry use wheat to protect fall sown seedbeds instead of using the traditional hydromulch. Wheat as a living mulch has many advantages as listed in Table 1. Possible problems are listed in Table 2.

Three basic methods are used to establish wheat depending on sowing method and seedling emergence characteristics. See table 3 for specific information on each tree species.

Method 1

For species with small seed that are sown with a pine seed drill, wheat seed is uniformly mixed with tree seed in a 1 to 1 ratio by weight. The seed drill is calibrated as usual with the knowledge that 1/2 of the seed is wheat by weight.

Our nurserymen use a calibration method based on weight. Calibration weights and good seed per pound data are run through a very simple computer program that produces information that allows unskilled personnel to calibrate the planter and permits easy monitoring of actual sowing rates. This method has reduced calibration time by 50 to 80% and allows calibration of tree seed-wheat mixes to be completed without extra effort.

Method 2

For seed sown with a walnut or oak planter, the tree seed is sown first, then wheat is spread over the sown beds at 2 bushels per acre using an Ezee flow spreader. The seed is covered with a rake or bedformer as appropriate for the tree seed sown.

Method 3

For seed that has a problem germinating if wheat is sown with the seed, the wheat is first broadcast over prepared beds and raked to cover. Then, the tree seed is sown by hand, broadcast, or drill sown and covered as appropriate.

The final step in using wheat as a living mulch is killing it with a herbicide in late winter or early spring. A general rule for timing of herbicide application is that wheat should be treated in late winter for small seeded tree species. This allows the wheat leaves and roots to begin decomposing by the time that seedling emergence begins. In southern Indiana, the herbicide would be applied to the wheat in February. For large seeded species the wheat is treated 1 to 2 weeks before seedling emergence. If tree seed is sown at a shallow depth (less than 1/2 inch) and the wheat stand is not heavy, the wheat can remain up to and after tree seedling emergence as long as a selective herbicide is used. The longer the wheat is allowed to grow, the better it functions in erosion and frost protection. This also delays emergence of tree seed to some degree.

Choice of herbicide used to kill the wheat will depend on the following factors. First, the pesticide label must be followed. Second, if the tree seed has not begun to emerge, a broad spectrum herbicide that has no soil activity can be used with the result that wheat and any emerged weeds will be killed. This is a major advantage if

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

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winter annuals have infested the seedbeds. Third, if the tree seed have begun to emerge a herbicide that will not damage the tree seedlings must be used.

Glyphosate, Paraquat, and Fluazifap-P-butyl have been used at the Vallonia Nursery. Paraquat and Glyphosate must be applied before tree seedling emergence. Fluazifap-P-butyl can be applied to many species of emerged tree seedlings. Be sure to read the label as some herbicides should be applied before the wheat reaches a certain growth stage.

Table 1. Advantages of Wheat as a Living Mulch.

1	Prevents wind and water erosion.
2	Protects seed from extreme winter temperatures.
3	Reduces frost heaving of seed.
4	Reduces seed loss due to predation by birds, squirrels, and deer.
5	Reduces nutrient leaching in the fall and winter.
6	Delays emergence of tree seedlings long enough to avoid most late spring frost.
7	Reduces soil compaction and adds organic matter to the soil.
8	Permits fall sowing on slopes that would otherwise erode severely.
9	Soil shading during mid-winter reduces possibility of seed germination during "January Thaw" weather.
10	Wheat is an indicator of soil fertility in spring before deficiency symptoms can be detected in tree seedlings.
11	Cost savings compared to hydromulch are between $400.00 & $600.00 per acre.

Table 2. Potential Problems with Wheat as a Living Mulch

1	Wheat must be killed at the correct time, otherwise seedling emergence will be reduced or delayed longer than desirable.
2	Sowing must be done early enough in the fall for the wheat to become well established before cold winter weather occurs.
3	If meadow mice are common in adjacent areas, these rodents may move into seedbeds if the stand of wheat is heavy.

Table 3: Methods of Using Wheat as a Mulch for Species Grown at the Vallonia Nursery

Species	Method	Sowing Dates	Herbicide Application Dates
Black Cherry	1*	mid September to late October	late January to late February
Black Gum	2	mid September to late October	late January to late February
Black Oak	2	mid September to late October	mid march to mid April
Black Walnut	2	mid September to late October	mid march to mid April
Bur Oak	2	mid September to late October	mid march to mid April
Cherrybark Oak	2	mid September to late October	mid march to mid April
Green & White Ash	1 or 3	mid September to late October	late January to late February
Pecan	2	mid September to late October	mid march to mid April
Persimmon	2	mid September to late October	mid march to mid April
Red Oak	2	mid September to late October	mid march to mid April
Shingle Oak	2	mid September to late October	mid march to mid April
Swamp Chestnut Oak	2	mid September to late October	mid march to mid April
Swamp White Oak	2	mid September to late October	mid march to mid April
Tuliptree	3	mid September to late October	late January to late February
Washington Hawthorn	1	mid September to late October	late January to late February
White oak	2	mid September to late October	mid march to mid April
White pine	1	mid September to late October	late January to late February

Green manure effects on soilborne pathogens

Jeffrey K. Stone
and Everett M. Hansen [1]

Abstract – Green manures from cover crops incorporated into nursery soils stimulated growth of pathogenic soil fungi. Bare fallow treatments reduced populations of soil pathogens to levels comparable to standard chemical fumigation. Seedling disease and quality were adversely affected by higher levels of pathogens in unfumigated cover cropped treatments, but were comparable in unfumigated bare fallow and standard chemical fumigation treatments.

INTRODUCTION

Cover crops have been traditionally used during non production rotations in nurseries for a variety of reasons (see paper by Robin Rose, this volume). One of the commonly cited benefits of using cover crops in the cultural sequence is the addition of organic matter to soils. Cover crops are most often incorporated by plowing under at maturity, either in the fall or spring, as a green manure. The addition of cover crop green manures, however, causes increases in populations of soil borne fungal pathogens (Hansen et al. 1990, Hamm and Hansen 1990). Incorporation of cover crop residues provides a nutrient resource that stimulates growth and reproduction of soil fungi such as *Fusarium* and *Pythium* spp. which can be opportunistic pathogens. Most nurseries that operationally employ a cover crop green manure in their rotation also routinely employ soil fumigation after incorporation of the cover crop and before sowing production seed to reduce populations of pathogenic fungi and other nursery pests, e.g. pathogenic nematodes, insects, and weeds (Landis and Campbell 1988).

It should be noted that all of these aforementioned cultural problems corrected by soil fumigation may be contributed to or aggravated by the practice of incorporating cover crops as green manures. The need for routine soil fumigation may be reduced or eliminated entirely by eliminating cover cropping from the cultural sequence. By keeping nursery beds fallow for one season between production cycles, the nutrient resources of the soil become depleted, and populations of soil pathogens decline correspondingly. Hansen et al. (1990) reported that population levels of *Fusarium* and *Pythium* spp. from fallow, unfumigated plots and cover cropped, fumigated plots were comparable by the spring following fall fumigation.

Rapeseed (*Brassica* spp.) has been suggested as a potential cover crop that may reduce the levels of various nursery pests. The basis for this suggestion is that species of *Brassica* contain as natural secondary metabolites glucosinalates, a family of thioglucoside molecules found in members of the Cruciferae. When the glucose is cleaved off in a chemical reaction catalyzed by the enzyme myrosinase, which also occurs naturally in the *Brassica* plants, a variety of chemical products are released, depending on the structure of the particular glucosinalate species (Figure 1). Among the products released by this reaction are isothiocyanates (Höglund et al. 1991, Appelqvist and Josefsson 1967, Fenwick et al 1983, VanEtten and Tookey 1983). Many isothiocyanates have potent antimicrobial activity, and methyl isothiocyanate is the primary active ingredient of several widely used commercial soil fumigants (Landis and Campbell 1990). The occurrence of glucosinalates and myrosinase in *Brassica* plants may help confer resistance to certain pathogens (Rawlinson 1979, Mithen and Lewis 1986, Greenhalgh and Mitchell 1976, Holley and Jones 1985, Walker et al. 1937).

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

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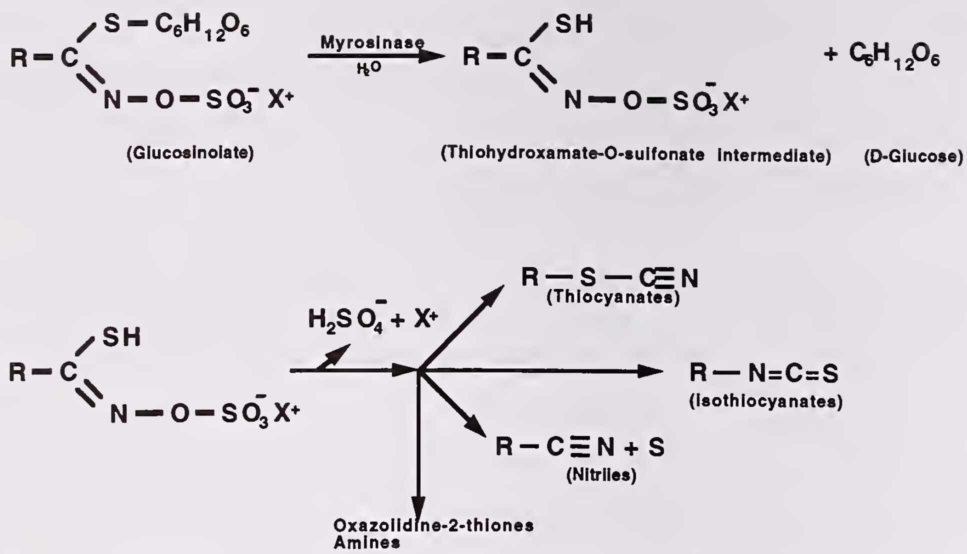

Figure 1. Pathway and products of myrosinase-catalyzed hydrolysis of glucosinalates. Based on Pessina et al. 1990.

Brassica residues used as soil amendments have been reported to reduce diseases caused by *Fusarium oxysporum* f. sp. *conglutinans* ("cabbage yellows") (Ramirez-Villapudua and Munnecke 1987) and *Aphanomyces* root rot of pea (Papavizas 1966, Chan and Close 1987, Muelchen et al. 1990). Brassica cover crops mown down at maturity and incorporated into soils as green manures therefore might reduce the populations of soilborne pathogens through the release of fungicidal isothiocyanates in the same way as some commercial fumigants.

During the past several years, a collaborative research project at Oregon State University has investigated the potential for using soil amendments, rapeseed cover crops, and bare fallowing in bareroot forest nurseries as alternatives to routine chemical soil fumigation. Populations of soilborne pathogenic fungi, incidence and severity of seedling disease, and seedling quality were assessed in nursery plots with Brassica cover crops, sawdust, and/or rapeseed meal soil amendments and compared with bare fallow and standard nursery cover crop-soil fumigation procedures in nurseries in Oregon and Washington. This paper reports some of our results to date.

METHODS

The study was located in a production field in the Bend Pine Nursery, Bend, Oregon. A full description of the climate and soil characteristics of this nursery can be found in the USDA Forest Service Pacific Northwest Region Nursery Pest Management Final Environmental Impact Statement (Anonymous 1989). The block in which the study plots were located had been fumigated with methyl bromide/chloropicrin in the fall of 1989 and the study was installed and cover crop sown in April 1990. The study block was comprised of eight contiguous beds in a 50 ft x 400 ft block which was divided into 24 plots, 18 x 50 ft. Four replicates of 6 treatments were established in the block: Bare fallow, *Brassica hirta* cv. 'Humus' cover crop (with and without sawdust amendment), Russian pea cover crop with methyl bromide fumigation, bare fallow with rapeseed meal (cv. Dwarf Essex) added at 6000 kg/acre, *Brassica hirta* cv. 'Humus' cover crop amended with rapeseed meal (cv. Dwarf Essex) at 6000 kg/acre.

Soil samples were collected at four intervals during the cultural cycle: at the time of sowing the cover crop (May 1990), at cover crop maturity (Aug 1990), following fumigation or cover crop incorporation (October 1990), and prior to conifer seed sowing (May 1991). Soil samples were processed as described by Hansen et al. 1991 for estimation of *Fusarium* and *Pythium* populations.

Brassica biomass was determined from collections taken at cover crop maturity from two randomly located subplots, 1 sq. meter each, for each replicate for each treatment. Subsamples of mature *Brassica* plants were also collected for glucosinalate analysis.

Seedling density and mortality were assessed at 2-week intervals in two, 0.5 x 4 ft. fixed plots per replicate for each treatment, commencing at 4 weeks following sowing. . At the end of the first growing season, seedling height and caliper were determined from four, 0.5 x 4 ft. plots per replicate plot for each treatment. Root biomass was determined from 25 seedlings dug from each replicate for each treatment. At lifting, the numbers of shippable seedlings were compared for samples from each replicate plot for the bare fallow and standard methyl bromide fumigated treatments.

Fusarium and *Pythium* populations, seedling density, mortality, height, caliper, and root biomass

were analyzed by analysis of variance procedures using Statgraphics and SAS statistics software. Count data were square root transformed and proportional data were log transformed as recommended by Sabin and Stafford (1990) prior to analysis. Multiple comparisons were computed using the method of Scheffé (Sokal and Rohlf 1981).

RESULTS

Fusarium and *Pythium* populations

Initial *Fusarium* populations were low, generally below 2000 propagules per gram, and relatively uniform throughout the study area. In cover cropped treatments, populations either increased slightly from initial levels, or remained near initial levels at cover crop maturity. *Fusarium* populations increased to well above initial levels after mowing and incorporation of *Brassica* cover crops. *Fusarium* numbers then decreased somewhat by the spring pre-sow sampling, but remained much higher than initial levels. In bare fallow treatments *Fusarium* populations declined from initial levels throughout the growing season until the following spring before sowing the conifer seed. Chemical fumigation in the Fall reduced *Fusarium* populations to below detection in the two fumigated treatments, but by spring, populations had begun to recover. *Fusarium* populations for all treatments were statistically homogeneous for the initial sampling and mature cover crop sampling periods. By the spring pre-sow period, two distinct

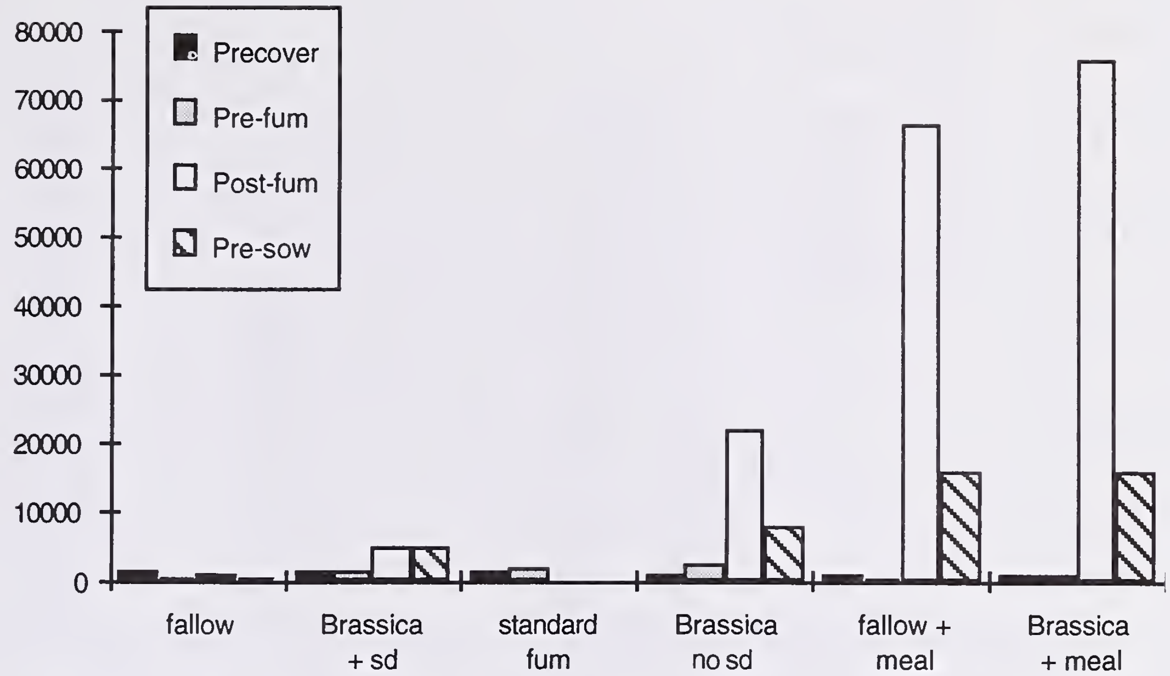

Figure 2. Averaged *Fusarium* levels (propagules per gram) in soil sample from four replicates of each of six treatments collected at four sampling periods in 1991 - 1992. Brassica + sd is sawdust amended treatment (all treatments had sawdust applied except Brassica no sd).

statistical groups were evident, bare fallow and chemical (methyl bromide) fumigation comprised one equivalent statistical group, the two *Brassica* cover crop treatments comprised the second group.

Pythium populations followed a pattern of response to treatments similar to *Fusarium* (Figure 3). Initial populations were relatively low and uniform throughout the study area and either increased slightly or remained near initial levels through the growing season to cover crop maturity. At cover crop maturity, *Pythium* levels were much greater than for the bare fallow or either *Brassica* cover crop treatments, apparently an effect of the pea cover crop. After cover crop incorporation, sharp increases in *Pythium* numbers were found. In contrast to *Fusarium*, the *Pythium* populations did not decrease between the fall and spring samples, but continued to increase, so that by the time of spring sowing the populations in cover cropped treatments were much higher than the initial levels of the previous spring. In bare fallow plots, *Pythium* populations remained near initial levels during the growing season, with populations decreasing by the spring pre-sowing sample to below 60 ppg. *Pythium* populations at pre sow sampling were significantly lower than populations in *Brassica* cover cropped plots. *Pythium* is more sensitive to fumigation than *Fusarium*, and fumigation resulted in a reduction of *Pythium* populations to below detection which persisted through the spring pre-sow sampling. As for Fusarium, the presow *Pythium* levels were statistically equivalent for the bare fallow and chemical fumigation treatments, and different from the *Brassica* cover crop treatments.

The increased levels of *Pythium* and *Fusarium* following incorporation of the *Brassica* cover crop compared to lower levels in chemically fumigated and fallow treatments, indicates that

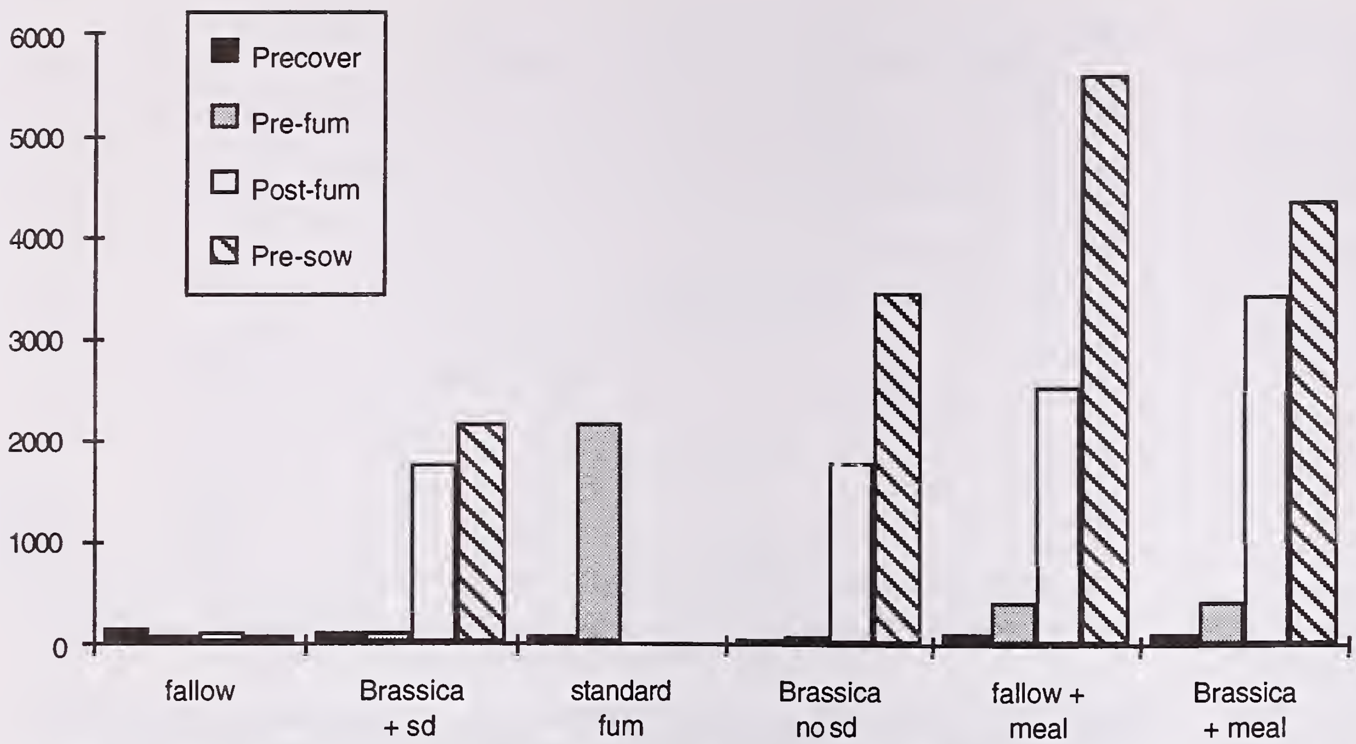

Figure 3. Averaged *Pythium* levels (propagules per gram) in soil samples from four replicates of each of six treatments collected at four sampling periods during 1991 - 1992.

fungitoxic byproducts of *Brassica* decomposition did not produce the expected reductions in soil fungal populations. Either these fungitoxic products were not produced in sufficient concentrations to reduce fungal populations, or additional growth and reproduction of the soil fungi on cover crop residues compensated for any population reduction. Based on biomass estimates of the *Brassica* cover crops and on glucosinalate concentrations in the mature plants, the amount of methylisothiocyanate produced on cover cropped plots would be equivalent to between one-third to one-half a commercial application of Basamid/Dazomet, assuming a 1:1 stoichiometry of conversion of glucosinalates to isothiocyanates.

Rapeseed meal

Additional treatments were designed to test the effect of supplementing glucosinalate-myrosinase concentrations in cover crop with rapeseed meal. Rapeseed meal is a waste product from oil extraction from the rapeseed and is higher in glucosinalate content than the vegetation residue. Based on glucosinalate analysis of the rapeseed meal, applications were made to plots approximately equivalent to a commercial Basamid/Dazomet application. Treatments were Brassica cover crop supplemented with rapeseed meal, bare fallow with rapeseed meal, and ryegrass cover crop with methyl bromide fumigation.

Immediately following incorporation of the rapeseed meal, *Fusarium* and *Pythium* populations increased sharply (Figures 2, 3). *Fusarium* populations in the *Brassica* with meal treatment were several times higher than those in the *Brassica* cover crop treatment, and more than 60 times higher than in the bare fallow treatment. *Fusarium* populations subsequently decreased during the winter, but residual populations in rapeseed meal supplemented treatments at the spring pre sow sample were still twice that of *Brassica* alone and 40 times that in the bare fallow treatment. *Pythium* populations continued to increase during the winter, so that by the spring pre-sow sampling *Pythium* populations on rapeseed meal supplemented plots were twice as large as those on *Brassica* alone and about 80 times greater than on bare fallow. Clearly the desired reductions of fungal populations did not result from increased quantities of *Brassica* residues , even those higher in glucosinalate content.

Seedling mortality

Methods for detecting and quantifying *Fusarium* and *Pythium* spp. in soil do not differentiate between pathogenic and non-pathogenic strains, and thus the propagule counts for these fungi in soils are not always correlated with incidence or severity of seedling disease. It is possible that fungal strains adapted to a non-conifer host, such as *Brassica*, may be benign to conifers. If these strains are non-pathogenic to conifers, then the higher populations resulting from incorporation of cover-crop residues might even beneficially interfere with colonization of seedlings by pathogenic strains. On the other hand, strains in nursery soils may be alternately saprohytes and opportunistic pathogens; higher levels of soil infestation may then lead to

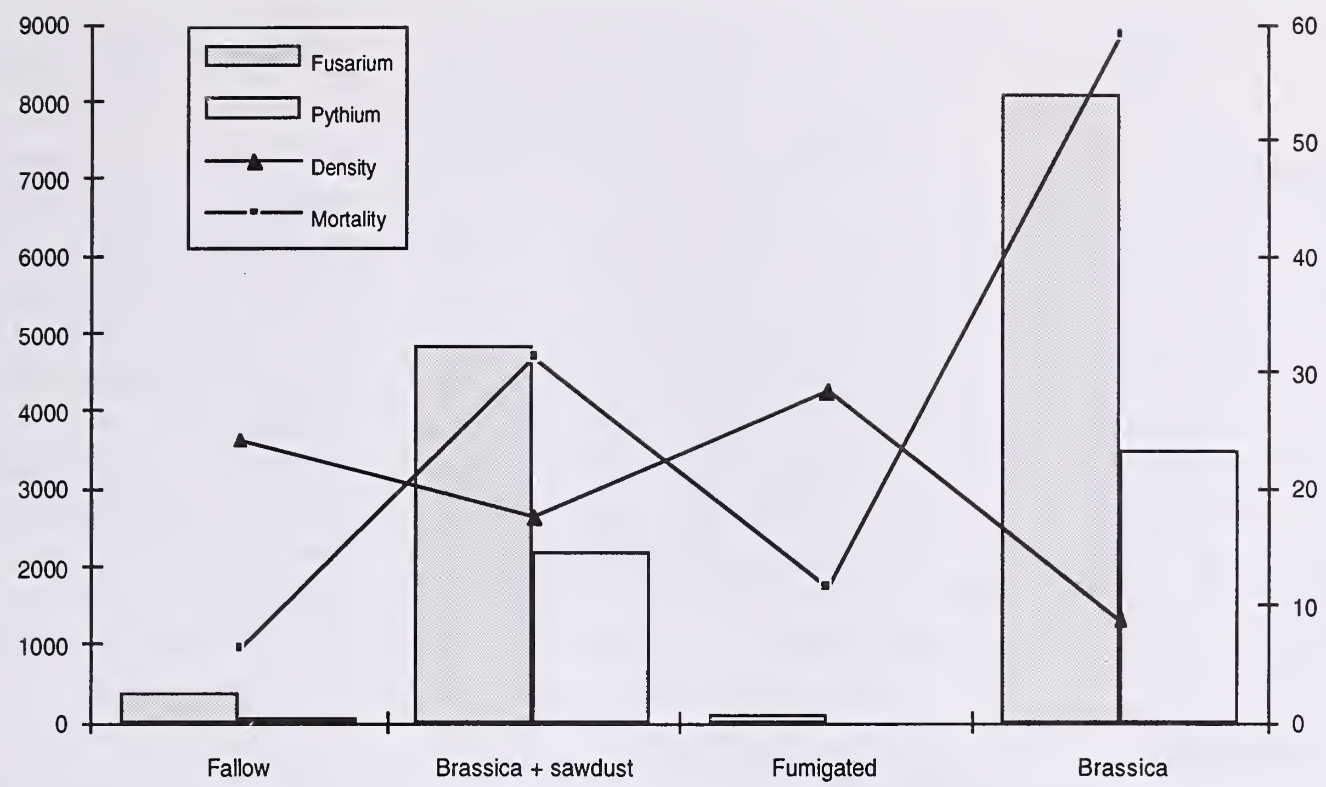

Figure 4. Seedling density (1-0) and post emergence mortality compared with pre-sow levels of *Fusarium* and *Pythium*.

increased disease potential. It is important therefore to evaluate the effects of cover crop treatments with respect to seedling disease as well as fungal populations.

Seedling density, the number of surviving germinants per sq foot, is an indirect measure of pre-emergence and early post-emergence mortality (damping off). Seedling densities were significantly different among different treatments, and these differences were inversely related to presow levels of *Fusarium* and *Pythium* spp. (Figure 4). Average seedling density was highest in the chemically fumigated plots, 28 seedlings/sq. ft. ,although not statistically different from the density in bare fallow plots, 24 seedlings/sq.ft. Average density was lowest in the *Brassica* without sawdust treatment, which was statistically different from the other three treatments.

Post-emergence seedling mortality, the percentage of seedlings with identifiable symptoms of *Fusarium* diseases, was also significantly different among the different treatments, and was positively correlated with presowing levels of *Fusarium* (Figure 4). Bare fallow and methyl bromide fumigation treatments were again statistically equivalent with respect to seedling mortality. Average post emergence mortality was actually lower in the bare fallow treatment (6%) than in the methyl bromide fumigation treatment (11%). Mortality was much higher in the two *Brassica* cover crop treatments (31 and 59%); these treatments were significantly different from each other as well as from the bare fallow and fumigated treatments with respect to seedling mortality. Mortality was so severe in the rapeseed meal amended treatments that data were not collected.

Seedling height, caliper, and root biomass

Seedling size and vigor also varied with treatment. Average seedling height was greater in the fumigated (7.1 cm) and the bare fallow treatments (6.9 cm) and these were statistically homogeneous. Seedlings were significantly smaller (4.9 and 5.1 cm) in the two *Brassica* treatments. There was a similar pattern among treatments for root weight, although differences between treatments were not as large Figure 6). Average root weight was greatest for the fumigation treatment (1.2 g). Bare fallow and fumigation treatments were statistically equivalent for root biomass, however only fumigation, but not bare fallow differed significantly from the *Brassica* treatments. Seedling caliper was homogeneous for all treatments (Figure 6). Severe mortality in the rapeseed meal amended plots

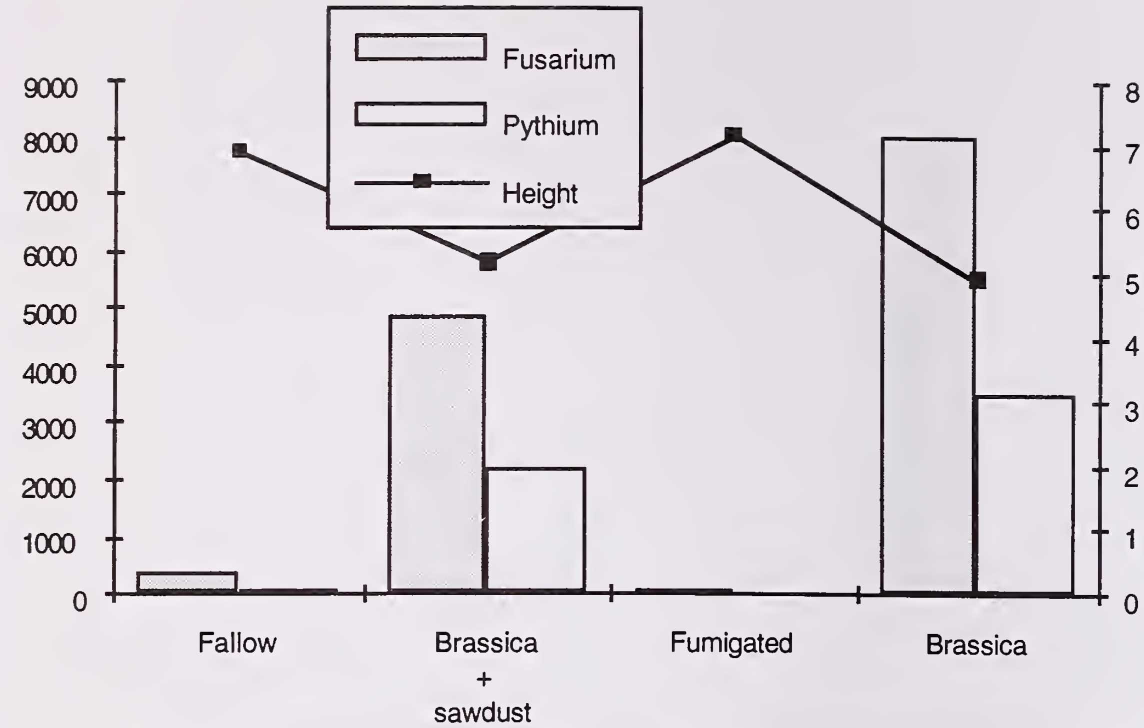

Figure 5. Average seedling height (1-0) compared with pre-sow levels of Fusarium and Pythium.

prevented data collection for those treatments.

Shippable seedlings

At lifting, the percent of shippable seedlings was determined from samples within each replicate plot for bare fallow and methyl bromide treatments according to standard nursery quality evaluation. Seedlings from the *Brassica* treatments were not assessed, inferiority of seedlings from these treatments has been described. The mean percent shippable seedlings from the bare fallow treatment was 81.3, the average for the methyl bromide treatment was 87.5; the means were not statistically different.

Effect of sawdust amendment

Fusarium and *Pythium* populations were lower in the *Brassica* with sawdust amendment than in the unamended *Brassica* treatment. These differences may partially reflect differences in *Brassica* biomass for these two treatments, which would directly influence fungal populations. Biomass of the unamended *Brassica* cover crop averaged 2.42 metric tons, about 30% greater than that of the sawdust amended treatment, 1.86 metric tons. Although additional fertilizer was added to the sawdust amended treatment to compensate for the increased microbial nitrogen consumption from sawdust decomposition, nitrogen deficiency probably accounts for the reduced biomass.

There is also however, an indication of possible suppression of disease in the sawdust amended *Brassica* treatment compared to the unamended treatment. Seedling density was lower in the no sawdust than in the sawdust amended treatment, which was not statistically different from the bare fallow treatment with respect to density. Post emergence (*Fusarium*) mortality was also higher in the unamended than in the sawdust Brassica treatment, which was statistically equivalent to the fumigated treatment with respect to *Fusarium* mortality. An earlier study of organic amendments at Bend nursery identified sawdust as a potential method for reducing *Fusarium* root disease, stimulating populations of beneficial microbes, and adding soil organic matter (Lu 1968), and other studies in northwest nurseries have reported reductions of *Fusarium* populations by sawdust additions (Hamm and Hansen 1990).

CONCLUSIONS

Brassica cover crops did not result in reduced populations of soil fungi, instead fungal populations increased in cover crop treatments and with additional *Brassica* residues (rapeseed meal). Cover crops incorporated as green manures are likely to result in increased levels of opportunistic pathogens, a situation that has routinely been corrected by chemical fumigation. Bare fallowing, on the other hand may afford a reduction of soil borne pathogens equivalent or comparable to that obtained by periodic fumigation, and enable seedling mortality and quality to be maintained with reduced use of chemical microbicides. Additional benefits of non-fumigation should be the establishment of more stable communities of soil microbes that should be less vulnerable to periodic invasion and colonization by opportunistic pathogens such as *Fusarium* spp. The establishment of stable soil microbiota, with effective competitors and antagonists to *Fusarium* spp.

should be the future objective for reduction of disease losses in conifer nurseries.

With the removal of the soil fumigant methyl bromide pending, and with costs associated with chemical fumigation increasing, nurseries are naturally anxious to find alternatives for control of nursery pests. The results of our research suggest that bare fallowing should be considered as an alternative to chemical fumigation. Bare fallow and chemical fumigation were statistically equivalent with respect to the levels of potentially pathogenic soil fungi recovered, in the levels of seedling mortality, and with respect to seedling quality after the first growing season. We do not advocate bare fallowing as a substitution for soil fumigation where extreme persistent pest problems exist, but feel that as a management option bare fallowing has been underutilized. From the standpoint of disease management, our experiments show bare fallowing to be the only non-chemical strategy to achieve levels of control comparable to those obtained from chemical fumigation. It is emphasized that scrupulous control of weeds must be maintained in order for bare fallowing to be effective in controlling pathogen populations. It seems likely that improved control of soil borne pathogens can be achieved under bare fallowing through a combination of organic soil amendments, such as sawdust, to promote microbial antagonists of pathogens, periodic cultivation to expose fungal spores, weed seeds and germinants to desiccation, management of fertilization and irrigation, and judicious use of chemical pesticides. Potential advantages of bare fallowing compared to other disease management options include:

1) nurseries have the capability to implement this practice immediately
2) bare fallowing in combination with periodic cultivation may also help control weed problems
3) beneficial soil microbes may build populations in soils not routinely fumigated
4) of the alternatives, bare fallowing seems to hold the most promise for providing a long term reduction in pathogen populations
5) costs will probably be lower than for routine chemical fumigation.
6) alternative fumigants to methyl bromide may have improved efficacy when used in combination with bare fallow.

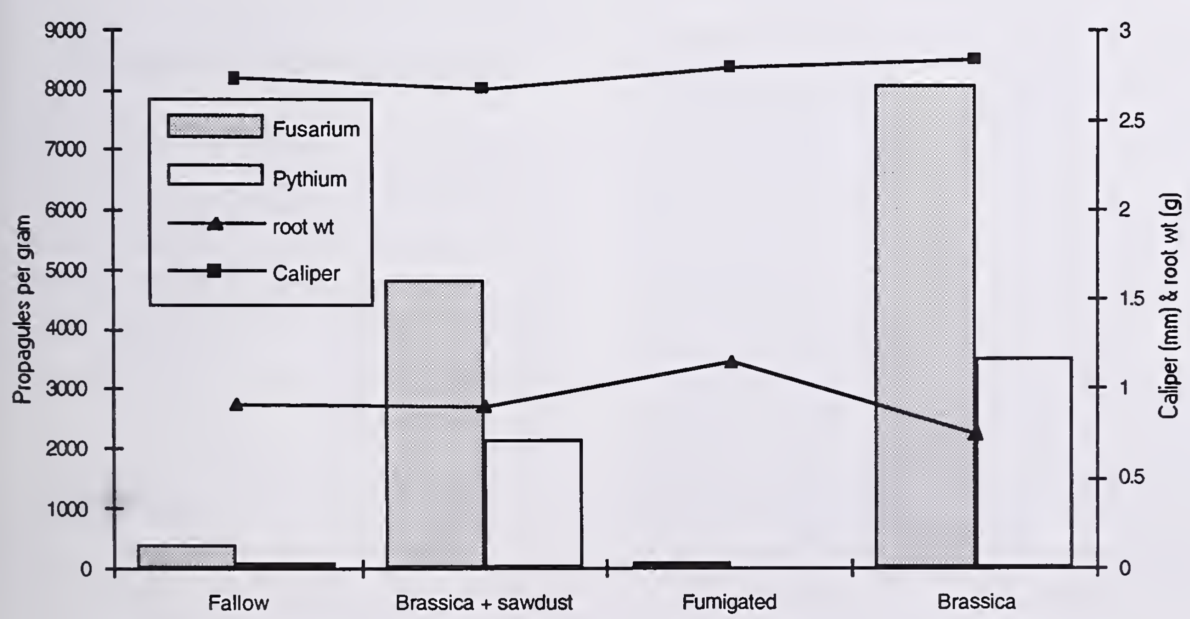

Figure 6. Average seedling root biomass and caliper compared to pre-sow levels of *Fusarium* and *Pythium*.

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ACKNOWLEDGMENTS

The assistance of Mahlon Hale and Bend Pine Nursery is gratefully acknowledged. A portion of this work was supported by the USDA Forest Service, Forest Pest Management, Technology Development Grant.

Using Municipal Organic Wastes at Lincoln-Oakes Nurseries[1]

Abstract – discusses the use of municipal organic waste in the forms of leaves, thatch, and grass clippings which are stockpiled and spread onto seedling production fields during the soil improvement rotation at the nursery.

Greg Morgenson[2]

INTRODUCTION

Towns and cities across the country generate sizable amounts of organic materials in seasonal care of lawns and gardens. These material include grass clippings, leaves, garden refuse, and lawn thatch. The bulk of these materials have ended up in landfills despite their recyclable potential. The City of Bismarck, ND estimates that during summer months, as high as forty percent of the refuse volume going into the city landfill is grass clippings.

During this period of landfill closures it is becoming necessary to limit materials going into landfills to conserve space and therefore increase the life span of the landfill. Lincoln-Oakes Nurseries, Bismarck, North Dakota, has began a program in cooperation with the City of Bismarck to utilize these materials in soil improvement rotations at the nursery.

Seedling nursery production returns little organic matter to the soil due to harvest of nearly the entire plant. Green manure crops and organic amendments such as peat moss or aged sawdust are typically used in field rotations to maintain desired soil organic matter levels. The availability of organic amendments in the plains states is limited and often the hauling distance makes their use nearly impossible. The use of locally available organic yard wastes would be of benefit both to the nursery and the city.

MATERIAL COLLECTION AND STOCKPILING

Collection of non-woody lawn refuse began in the spring of 1989 when local lawn care firms were allowed to dump clippings in a specified area at the nursery. In the fall of 1990 the nursery began accepting leaves from the City of Bismarck and in 1991 materials throughout the seasons were accepted from the city, homeowners, and lawn care firms. These materials are stockpiled for spreading, no composting of stockpiled materials takes place. (fig. 1)

Figure 1

[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

[2] *Nurseries Manager, Lincoln-Oakes Nurseries, Bismarck, North Dakota.*

Signs at the designated collection area were erected to specify types of materials wanted, types of materials not wanted, and what the organic materials were to be used for.

The city of Bismarck has placed collections bins throughout the city for homeowner use. These bins are emptied by the city several times weekly and materials are brought to the stockpile area at the nursery. The city has also fenced and asphalt capped the surface of the stockpile area to prevent materials from blowing and to provide a hard surface for trucks and the loader to operate on.

SPREADING AND INCORPORATION

The need to spread accumulated organic materials on a regular basis to minimize odor and to have the proper equipment to do it efficiently is essential.

Material should be spread onto fields every several seeks to prevent severe odor problems from developing. Materials are loaded into manure spreaders mounted on two ton single axle trucks (fig. 2) The nursery provides two of these trucks and the city provides one truck and the loader and operator. Materials are spread evenly by three to four passes over the entire field (fig. 3). Fields vary from approximately two to five acres in size and are in the first year of their soil building rotation.

After spreading, the materials are mixed into the soil with a heavy offset disc. A chisel plow and tiller have also been used for incorporation but the offset disc has been found to work best in the varying types of materials placed on the fields. Physical breakdown of the green grass clippings is rapid, dry thatch and leaves somewhat slower. Irrigation may be required to hasten breakdown.

Several additional passes with materials are made two to four weeks after the initial application and once again mixed into the soil. Further mixing is done periodically with the disc as needed to promote a fairly even breakdown. No nitrogen fertilizer applications have been necessary due to the high N content of the grass clippings. Fields need to be walked by summer crew members to remove trash and debris that was present in the materials when spread. All organic materials are retained in the upper twelve inches of the soil, this is the area of greatest root development of the seedlings.

Figure 2

COVER AND GREEN MANURE CROPS

Organic materials are applied to fields the first season of a two year soil building rotation. During the second season a cover crop is grown for at least part, if not all, of the growing season. These crops are allowed to grow to a desired height and then are mowed or disced down to further add organic matter content during the field rotation and to recycle nutrients. To date, no nitrogen inputs have been required to produce these crops.

Crops used

A Sudan grass - Spring planted on previously summer and fall applied fields, mowed several times during the growing season. Disced down in September.

B Oats - Summer planted as a winter cover on fields where organic materials were applied the previous spring. Winter kills.

C Rye - Fall planted on spring and summer

Figure 3

applied fields, over winters and is disced down at heading out stage the next spring.

All cover crops are incorporated into the top twelve inches of soil and allowed to breakdown before seeding tree and shrub crops in spring, summer, or fall. Fertilizer additions are as needed based on soil tests.

ADVANTAGES AND DISADVANTAGES OF ORGANIC WASTE APPLICATIONS

As with any new operation added to the nursery production schedule, there are pros and cons.

Advantages of organic material applications

1 Soil organic matter increase and associated benefits i.e. Water holding capacity, increased CEC

2 Recycling of organic materials otherwise disposed of in city landfill

3 Possible reduction in use of nitrogen fertilizers on cover crops following organic material applications

4 PR benefit with city and local citizens

Disadvantages of organic materials applications

1 Increased land requirements for the stockpile area and the increased length of field rotations by one year

2 Equipment requirements for loading and spreading

3 Odor problem from stockpiled and spread materials

4 Trash accumulation in fields and labor to remove it

The operation has obvious positive benefits for the nursery and the city but has resulted in complaints about odor from neighboring landowners. The amount of trash, i.e. plastic, metal, limbs, etc... being placed in the stockpile has been greater than expected and will need to be reduced to continue the program in the future. Many citizens of the city of Bismarck support this concept of recycling organic waste materials to aid in the production of woody plants for conservation purposes. It is the beginning of a long term process to realize future sustainable levels of nursery soil organic matter levels.

Integrated Pest Management In Canadian Forest Nurseries - Current Perspectives and Future Opportunities[1]

T. R. Meyer, M. Irvine, E.M. Harvey and T. McDonough[2]

Abstract – Concepts and practices of integrated pest management (IPM) from the applied perspective of the forest seedling grower in Canada are discussed. An overview of IPM in forest seedling production is provided; current status of IPM practices in Canada are outlined; and a continuing education opportunity for nursery professionals is introduced. Concepts, techniques and principles for planning, implementing and evaluating IPM programs are examined within the broader scope of Integrated Resource Management (IRM).

Integrated Pest Management (IPM) has been defined as: "...an approach to pest control that utilizes regular monitoring to determine if and when treatments are needed and employs physical, mechanical, cultural, biological and educational tactics to keep pest numbers low enough to prevent intolerable damage or annoyance. Least-toxic chemical controls are used as a last resort." (Oklowski et al. 1991).

REFORESTATION STOCK PRODUCTION

Nearly one million hectares of forest were harvested in Canada in 1990 (Anon. 1992a). During the period 1975-85 the area harvested increased from 680 to 900 thousand hectares, an increase of 32%. The percent of harvested area replanted increased from 19% in 1975 to 29% in 1985 (Kuhnke 1989). Despite these efforts, most provinces have a regeneration gap between the area harvested and the area regenerated either naturally or artificially.

Approximately 140 nurseries produce forest seedling planting stock in Canada. Container seedlings represent approximately 70% of total production, the remainder are bareroot seedlings (Canadian Forest Nursery Weed Management Association, unpubl. data). The proportion of seedlings produced in containers has increased dramatically from the approximately 17% of total production in 1975 (Kuhnke 1989).

Response to this increasing demand for planting stock is an increase in both absolute production and in production efficiency. To date, substantial increases in production efficiency are realized through refinement in cultural practices and reduction in losses, especially from pests. Economics of scale have increased efforts in this regard because of a diminishing cost per seeding to minimize pest losses. These forces influenced the relatively recent development of integrated pest management programs in seedling production throughout Canada and are responsible for regional differences in program development and practices. Accordingly, regions supporting the greatest demand for seedling production are often those with the most refined integrated pest management programs.

INTEGRATED INSECT AND DISEASE MANAGEMENT

Concepts and practices of integrated pest management in forest seedling production have been discussed and reviewed elsewhere (Daar et al. 1992; Hamm et al. 1990; James et al. 1992; Krelle et al. 1992; Linderman and Hoefnagels 1992; Olkowski et al. 1991; Stein and Trummer 1992; Sutherland 1991; Sutherland et al. 1990).

Seedling stock production, from the perspective of functional ecosystem diversity, is highly prone to insect and disease outbreaks (Schmidt 1978). In an applied sense, this means pest damage can occur quickly over a large area. This damage can occur randomly throughout the crop, and if temporally segregated, be undetected and untreated until late in the rotation. If the damage is aggregated, both temporally and spatially, then therapy is

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[1] Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993

[2] Forest Pest Management Institute, Canadian Department of Natural Resources, Sault Ste. Marie, ON, Canada

often applied with the concern towards continuing potential damage. Both of these responses are biased towards perception. Considerations of real and potential pest impact are based on a growers experience and judgement. The same situation is often true for pest preventative measures. The expressed level of concern is often based on perceived pest impact.

The increasing complexity in practicing integrated pest management, along with the increasing scope of liabilities associated with these actions, requires an even greater precision in management decisions. Accordingly, decision support is identified as a high priority in recent national strategic directions (Anon. 1992b). Thompson et al. (1992) have designed a prototype of an expert system for diagnosis of forest seedling nursery insect, disease and abiotic problems. The cornerstone of decision support from an integrated nursery pest management perspective is information on the impacts of specific pests and management alternatives. Impact information includes prediction to evaluate possible outcomes. Conceptually, this is simple; what level of damage is related to what level of pest, at what time, under what conditions. The same conditional parameters also apply to questions regarding environmental impact and public safety (Scholtes 1991; Dumroese et al. 1991; Landis et al. 1991; O'Hara 1991). The most sophisticated or effective nursery pest management practice is limited by constraints in this information. These are the exact questions, however, a nursery manager or grower must consider during the planning process and when a problem becomes evident. The high research priority assigned to these questions is further indicative of both the need and lack of information specifically as it pertains to nursery pest management.

The next order of nursery pest management decision support is integrating all the mentioned information, if it existed, for all potential pests and management practices. This task is incumbent and performed by the seedling grower since the responsibility for nursery stock production is usually theirs. From this discussion, the question of what is the procedure for formulating integrated pest management decisions with the lack of information is obvious. The answer is also obvious, those who are responsible to make decisions do so through experience and supposition.

An Ontario IPM example: Treating the symptoms, not the disease

Damping-off is considered a collection of diseases of similar symptomatology causing seedling losses during germination and early emergence. Many different species of fungi can be the causal agents, either independently or in combination. Disease losses are related to environmental conditions which retard germination and prolong early emergence. Traditional disease management included the coating or 'pelletizing' of powder formulations of fungicides, usually Captan or Thiram, to the seed coat prior to sowing. This practice was routinely followed because it was considered effective and did not harm the seed. The loss of these fungicides to the seedling grower, either through changes in use registration or regional restrictions, incited growers to rely more on the traditional practice of

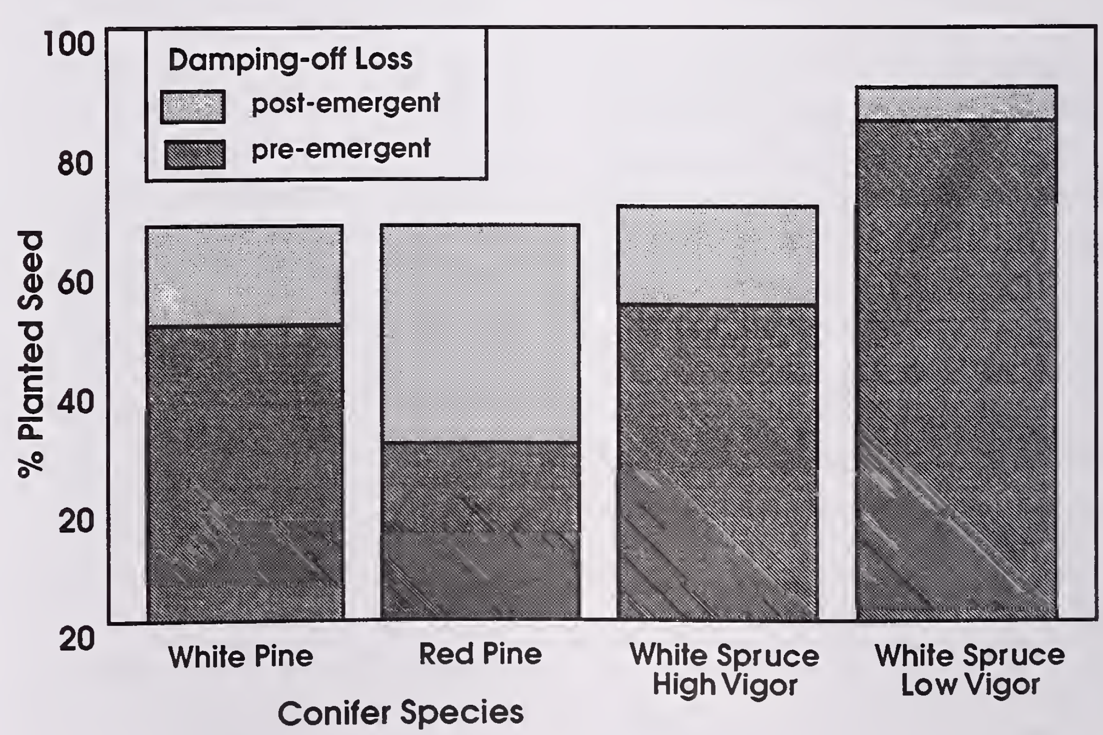

Figure 1 – Damping-off losses, Kemptville, Ontario, 1990

fungicide drenching of seed beds which is still in practice today.

In Ontario, many growers expressed concern regarding the lack of 'control' of damping-off losses, especially after drenching once mortality was observed. A request was made to search for 'newer' effective fungicides. Many assumptions of past management practices for damping-off needed to be reevaluated to effectively manage damping-off losses. Intensive monitoring of seed bed emergence and early growth demonstrated preemergence losses can account for over 80% (Fig. 1). Post-emergence damping-off was substantially less and appeared unrelated to pre-emergence losses. Traditional practices were mostly concerned with post-emergence losses. Pre-emergence losses were accounted for by high seeding density to ensure minimum numbers of seedlings. During growing seasons when damping-off losses were minimal seedling density was very high causing another order of disease problems from competition stress later in the life of the crop.

Information on the effectiveness of chemical control, nature of losses, and influence of the environment on disease biology provided for effective decisions in damping-off management. The basis for these strategies is, in a sense, biological control. Fungicides are no longer recommended, even if their use is registered, for social, environmental and biological reasons. Management efforts for damping-off are through promoting and maintaining seed quality as it pertains to germination vigour and contamination. It is recognized that damping-off losses are a direct function of the length of time that it takes for a seedling to become lignified. The quicker the germination and growth, the less likelihood of losses from damping-off. Disease management efforts involving methods of seed extraction, storage, handling, stratification, and precision sowing are successful in reducing losses from damping-off, and minimizing stress-related pests of older crops, and provide consistent crop production while virtually eliminating the use of traditional fungicide practices.

This example demonstrates the inter-relatedness of disease (and/or insect) problems and how a successful approach was achieved through applying the principles of IPM. Identification of the 'actual' problem regarding pest impacts was the first step in the decision process followed by 'treating' the disease through application of existing knowledge. This' win-win' example is very simple where the consequence of action is rarely with negative consequence or compromise. Root diseases in stock production, in contrast, often involve very complex interactions. Nevertheless, the same principles apply and information is critical to decisions in pest management.

INTEGRATED WEED MANAGEMENT IWM

Traditionally, IPM has dealt with insects and diseases. As the literature on these topics is voluminous, and as IWM is a relatively new concept in the field of IPM, this section will deal with specific tactics and strategies of IWM.

Swanton and Weise (1991) defined integrated weed management (IWM) as the application of numerous alternative weed control measures, which include cultural, genetic, mechanical, biological and chemical means of weed control. An individual control measure will not provide acceptable levels of weed control, but if the various components of an IWM are implemented in a systematic manner, significant advances in weed control technology can be achieved.

Development of an IWM strategy starts with an examination of the crop cultural system. Nursery culture of bareroot· seedlings begins with sowing in either late fall or spring into field beds. Seedlings will grow in the beds, with or without transplanting, for a total of one to four years, depending on species and location. The low end of this range would be for fast-growing hardwoods in warm parts of Canada; the high end of the range would be for conifers in more northerly nurseries. An alternative scheme is to start the seedlings as plugs in a greenhouse, and then transfer them to nursery beds to reach target size for outplanting. The cultural systems that have developed in particular areas have generally proven to be the length of time required to grow a tree with acceptable size (as measured by height and root collar diameter) and thus able to cope with competition after outplanting. Grower preference and nursery history also influence the type of stock grown in particular nurseries.

Tillage system

Swanton and Weise (1991) give a strategy for the type and relative order of studies needed in the development of an IWM program. The place to begin to improve weed control in a crop is by re-examining tillage practices. The trend in agricultural production to reduced tillage systems cannot be applied to bareroot nursery culture. This perennial system is already no-till for all but one year of a crop growing cycle when a destructive tillage is unavoidable at the time of lifting.

Critical period of weed interference

The second part of the Swanton and Weise (1991) plan is the study of critical period of weed interference. This was defined by Weaver and Tan (1983) as the specific minimum period of time during which the crop must be free of weeds in order to prevent yield loss (growth reduction). Its two components are the length of time weeds can remain in a crop before growth reduction begins, and the length of time that weed emergence must be prevented so that subsequent weed growth does not reduce crop yield (Weaver and Tan 1983). These components are experimentally determined by measuring crop yield loss as a function of successive times of weed removal or weed emergence, respectively (Weaver et al. 1992).

The traditional way to analyze critical period information has been to compare crop yields achieved after various periods of weed infestation or weed control through use of a multiple comparison procedure such as Duncan's New Multiple Range (DNMR) test or Student-Newman-Keuls (SNK), though such procedures were not suitable for structured data such as these (Warren 1986; Cousens 1988). Cousens (1988) recommended the use of regressions to describe the data.

Several mechanisms have been proposed for the basis of competition, as explanation for results observed in critical period studies. For example, interference with photosynthetic photon flux density (PPFD) interception has been implicated as the basis of weed competition. Weaver and Tan (1983) found that weed interference was primarily due to shading as opposed to water stress in transplanted tomatoes. Hall et al. (1992) found that increasing periods of weed interference achieved this effect by reducing the area of individual corn leaves, and by hastening the senescence of older leaves.

In forest nurseries, critical period information is useful because it tells us when to allocate limited budgets for costly inputs such as handweeding in order to maximize benefit. It is an important first step in developing an integrated weed management strategy.

Alternative methods of weed control

The third part in the development of an IWM strategy as outlined by Swanton and Weise (1991) is the examination of alternative methods of weed control, including such things as cover crops, cultivation and biological control. All three have limited applicability to the nursery system. Juzwik and Testa (1991) found that the use of cover crops of alfalfa (Medicago sativa L. cv. Vernal) or Sudan grass (Sorghum bicolor (L.) Moench, cv. Green Leaf) led to increases in the levels of Cylindrocladium sp. in the soil. Cylindrocladium sp. is a damaging and persistent pathogen of spruce seedlings. The use of cover crops such as Sudan grass, oats (Avena sativa L.) beans (Phaseolus vulgaris L.) or peas (Pisum sativum L.) increased the population densities of Fusarium spp. and Pythium spp. when compared to bare fallow controls in a conifer nursery (Hansen et al. 1990). Both Fusarium and Pythium have been implicated as pathogens of conifer seedlings. Other cover crop species have had a neutral (spring wheat, Triticum aestivum L. cv. Glen Lea) or deleterious (flax, Linum usitatissimum L.) effect on Cylindrocladium populations (Juzwik and Testa 1991). Clearly the considerable danger of a wrong choice and the inconsistent weed control benefits (Moore 1992) associated with cover crops limit their usefulness in a forest nursery IWM strategy. Despite these problems, the use of companion crops has the potential to reduce the use of shades to provide protection from excessive sun and wind.

In the nursery system, a companion crop of spring wheat should be neutral to pathogens, and provided it is not allowed to grow too tall, should not interfere with PPFD interception any more than wooden shades. Root development of a spring wheat companion crop would be drastically reduced as a result of applications of chlorthal-dimethyl or

napropamide. As nutrients are applied to the nursery crop at luxury levels, and water is applied through irrigation as required, a spring wheat companion crop should not compete with nursery stock. A spring wheat companion crop would result in substantial cost savings if the use of shades could be reduced.

Interrow and bed cultivation is already being practised in many Canadian nurseries, although there may be some room for improvements of equipment, timing and techniques. Problems of tight row spacing in the beds, shallow rooted crop plants, and the potential for interference with preemergence herbicides limit the usefulness of this technique to some extent.

Likewise, classical biological control is of very limited value because in the nursery system many weed species are present and interfering with nursery production. Inundative biological control (bioherbicides) may be useful but given the regulatory environment, these fall under the same restrictions as herbicides, and more data are required for registration of these products.

Enhancement of crop competitiveness

Swanton and Weise (1991) suggest cultivar competitiveness, planting pattern and nutrient placement as methods to enhance crop competitiveness.

There are two factors limiting our ability to improve cultivar competitiveness:

1 In forestry in Canada, selection in most nursery crops is not being practised except to collect seed from sources that have consistently produced good seed in the past. This is changing as seed orchards come into production, but because of the long life cycle of forest trees, we will always lag behind agriculture in our ability to improve crop competitiveness through selection.

2 Unlike agricultural crops, the attributes that improve nursery competitiveness may not be the same attributes that are desirable in forest trees.

The goal of improving cultivar competitiveness is worthwhile, but a very long-term goal.

Improving planting pattern has already paid benefits in the nursery system. Precision vacuum seeders were first introduced to the nurseries over five years ago, and are now used for most crop seeding. These have improved crop competitiveness by increasing the uniformity of the stand, thereby reducing intraspecific competition and increasing the growth rate.

In theory, nutrient placement should offer benefits by making nutrients more available to the crop and less to the weeds. In reality, nutrients are applied to the seedlings at luxury levels to bring seedlings to target shipping size within a reasonable period of time. There may be benefits in the use of a nitrification inhibitor to keep applied nitrogen in the ammonium form, available to the gymnosperms, but not to weedy angiosperms. This would be an interesting study, that could potentially lead to better fertility management in the nurseries.

MODELLING OF CROP-WEED INTERFACE

Using approaches such as the critical period of weed removal, and models of growth under competition or free of competition, we can understand the dynamic interaction between weeds and the nursery crop.

Crop rotation and seed bank dynamics

Bazzaz (1979) defined succession as a process of continuous colonization of, and extinction on a site by species populations. Arable land is a special successional case, being characterized by regular, recurrent and often highly predictable disturbance (Bunting 1960). Froud-Williams (1988) stated that the composition and density of weed floras are, in general, a reflection of the crop production and agronomic practices employed. In agriculture, including nursery culture, weed populations can respond to changes in cultivation (Froud-Wiliams et al. 1983; Chancellor 1985), fertilization (Pysek and Leps 1991) or herbicide regime (Roberts and Neilson 1981; Mahn and Helmecke 1979). Understanding how nursery cultural practices influence weed communities will help us plan IWM strategies that do not create problems, such as when overuse of a preferred herbicide leads to problems with escapes of weeds that are tolerant of that herbicide. An example is triazine-resistant weed biotypes, a result of overuse of triazine

herbicides such as prometryne and simazine.

Current practices

Weed control in container production is achieved through use of weed free growing media, and sanitary measures such as controlling the weeds in the floors of greenhouses and cold frames, and in holding areas. In enclosed structures, filtering the air during times of much airborne seed reduces weed establishment. Handweeding is the major means of controlling weed escapes, with limited use of postemergence herbicides such as glyphosate. Preemergence herbicides such as napropamide are also used in some situations to prevent weed establishment in containers.

Weed control in bareroot production may begin after crop sowing but before seedling emergence with an application of a nonselective postemergence herbicide such as glyphosate to kill emerged weeds. This stale seedbed method is gaining acceptance because nurserymen have very few options for postemergence weed control in the established crop.

DCPA is applied at the time of sowing in conifers at some nurseries, because other registered herbicides are not tolerated then. Following the movement of the apical meristem away from the cotyledonary whorl (usually six to ten weeks after sowing), napropamide is well tolerated and can be applied. Simazine, napropamide or mixtures of these herbicides are used for seedbeds older than one year or for transplants. A registration for oxyfluorfen is being sought because the preemergence herbicides thus mentioned have serious gaps in weed control, and a problem with triazine resistance has been found at some nurseries. Directed applications of glyphosate are used in the growing crop, and handweeding and mechanical cultivation are also used. Applications of 2,4-D are tolerated by dormant conifers and are used for end of season control of broadleaf weeds. Fluazifop is registered for grass control and can be used at any time during the season. Conifers are generally shipped as 2-0 or 3-0 seedbed stock, or as 1-2, 2-1, or 2-2 transplants. There is a trend towards growing more transplants from greenhouse stock, with a G-1 or G-2 the final bareroot product.

Napropamide is usually applied before crop emergence in hardwoods and reapplied in the first season of growth. Simazine or napropamide or mixtures of the two are used on older hardwoods. Glyphosate is sometimes used prior to budburst in spring for early season weed control. Fluazifop, mechanical and handweeding are used in hardwoods as in conifers above. Hardwoods in Canada are generally shipped as 2-0 stock, except hybrid poplar and walnut, both of which are shipped as 1-0.

CONTINUING EDUCATION

Research is only useful if it is accompanied by is a continuing education program to ensure adoption of new strategies and tactics by nursery growers. Precision in judgement by experienced nursery professionals can be enhanced by a strong continuing education program in IPM. The Department of Natural Resources through the Forest Pest Management Institute has addressed the issue of expert training in the IPM by spearheading the Advanced Forest Pest Management Training Program (AFPM), a series of courses in Forest Pest Management. The AFPM, through advanced courses directed towards experienced motivated individuals, provides detailed expert level training in forest pest management that is not within the scope of other continuing education opportunities for resource management professionals.

Integrated Pest Management For Forest Nurseries Course

North America is endowed with a wealth of technical expertise in the field of integrated pest management for forest nurseries. Practical strategies and tactics are available for managing insects, diseases and competing vegetation in an integrated fashion, however often this knowledge is not effectively relayed to the operational nursery people. If nursery managers are to realize the goal of integrated pest management, it is essential that opportunities be created to allow these individuals to acquire expert training that presents multi-disciplinary information in a collated and practical manner.

The Integrated Pest Management Course For Forest Nurseries examines IPM for forest tree nurseries within the context of the following nursery goals:

1 produce high quality seedlings

2 produce needed seedling quantity

3 protect human health

4 protect environment

5 cost efficiency

In this course, pest refers to insects as well as diseases and competing vegetation. Control for some of the more common problems caused by abiotic (such as winter desiccation and heat damage) or cultural (such as fertilizer damage) factors are also discussed.

The course is presented in a ten day block. Education strategies such as lectures, group discussions, group projects, case studies, computer modelling sessions, field demonstrations and field trips are integrated in order to provide for different learning styles. New ideas and approaches are developed from featured evening speakers addressing forest pest management from a variety of perspectives.

The course is divided into main subject areas or modules. The modules are developed as intensive learning packages that bring together the best available technical information on the subject. A typical module features a teaching team of 3 to 6 instructors over a 1 to 3 day time period. The teaching teams ensure that their topics are not only well presented, but learned in an effective manner. Participants frequently add to the depth of the learning experience by bringing their expertise forward in discussion and lecture periods.

Each module is linked to the others so that lessons are integrated in an applied manner. By the end of the course, participants view pest populations, treatment options, prevention options, social and environmental concerns, and other factors, as a dynamic array of considerations that need to be incorporated into a successful integrated pest management strategy.

Participants are evaluated by completing a course practicum. A nursery compartment or greenhouse is assigned to small groups who are charged with developing pest management strategies and prescriptions that are rationalized in terms of cost-effectiveness, environmental consequences and social acceptability. This exercise is completed over the two week period of the course, and the result of each group's work is presented to a discriminating audience of instructors, other course participants and interested members of the public. Written records of these group practicums are expected to be of sufficient quality to eventually become published as case studies in Forest Pest Management Program Planning Guides, targeted at the hands on users in the forest pest management industry.

This course is targeted towards practising nursery professionals. The basic requirement is extensive experience in forest tree nursery management.

A proposed course outline follows.

Module 1 - Introduction

This module provides participants with a "short course" on IPM in forest nurseries. IPM is defined. The unique elements of the forest nursery environment such as proximity to agriculture and residential areas and IPM in enclosed spaces are outlined. A basic background in pesticides including minimum requirements for certification, human health concerns and occupational safety is provided. Entry points for pests on the nursery such as greenhouses, bare root fields, outside compounds, and cold storage facilities are identified. The relationship between nursery cultural treatments and pest incidence is introduced.

Module 2 - Common Insect Pests

Common insect pests in the greenhouses, outdoor compounds, and bare root fields are discussed. Topics include detection, identification, life cycles, population inventories, monitoring systems and damage thresholds. Cultural, biological, and chemical control options are identified and discussed.

Module 3 - Nematodes and Common Disease Problems

Nematodes and common diseases in the greenhouses, outdoor compounds, bare root fields, and cold storage facilities are discussed. Topics include detection, identification, life cycles, alternate hosts, monitoring systems, and damage thresholds. Cultural and chemical control options are identified and discussed.

Module 4 - Vegetation Management

Common vegetation management problems in the greenhouses, outdoor compounds, and bare root fields are discussed. Topics include entry points for

competing vegetation into the greenhouses, outdoor compounds, and bare root fields, and tolerance thresholds. Cultural, manual and chemical control options are identified and discussed.

Module 5 - Rodents, Birds and Small and Large Mammals

Damage from rodents, small and large mammals, and birds are identified and described. Topics include identification of damage and how to make sure that damage is not caused by diseases or insects, tolerance thresholds and safety concerns. Options for control such as cultural and chemical control, deterrents and baits are identified and discussed.

Module 6 - Abiotic and Cultural Factors

Common problems in the nursery that are often confused with insect or disease symptoms are described. Topics include winter desiccation, heat damage, frost and fertilizer damage.

Module 7 - Response of Pests to Nursery Cultural Treatments

This module explores the relationship between nursery cultural treatments and pest incidence. Often cultural treatments to enhance growth, hardening off etc. are responsible for increasing pest problems in the nursery. Topics include fertilization, transplanting, root culturing, dormancy induction treatments, and cold storage.

Module 8 - Economics

This module explores economic inventory and cost/benefit models in relation to IPM in forest nurseries. Topics include assessment of the economic value of the goods and services supplied by the forest tree nursery, and assessment of the costs and benefits of various control options.

Module 9 - Management Strategies for Making Appropriate Decisions

This module will integrate the previous 7 modules in terms of decision making strategies. How a manager decides if a pest needs to be controlled, when to take action and what methods to use are discussed. The four features of effective pest management (clear goals, a planned decision-making process, realistic damage thresholds, and a choice of responses) are examined. Decision support and expert systems are introduced as tools for decision making strategies. Topics include developing an IPM plan for each pest, monitoring and analyzing pest situations, analyzing available control options to determine their impact on control options for other pests, evaluating treatment effectiveness and getting along with the neighbours and communications.

Practicum

The information presented in each of the modules will be integrated by completing the course practicum where participants will be given a greenhouse, nursery compartment, or outdoor compound to apply the information presented in the course. By the end of the course, participants will have fully evaluated the options for managing forest pests on that site.

For additional information on AFPM and suggestions for the Integrated Pest Management for Forest Nurseries Course, feel free to contact Eileen Harvey at the Forest Pest Management Institute (705-949-9461). This course is very much in the development stage and any input will be gratefully accepted.

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IPM Program for Ornamental Nurseries in Wisconsin[1]

Karen Delahaut[2]

Abstract – An Integrated Pest Management Program was developed to assist the growers of woody landscape plants in Wisconsin reduce their chemical pesticide inputs through educational instruction on pest identification and the implementation of a stock monitoring program. The nursery IPM program offered alternative pest management options along with the timely implementation of traditional strategies. Educational programs gave growers the opportunity to sharpen their pest identification skills which in turn improved their pest management ability.

The Nursery IPM Program began in May 1991. Funding for the program was provided by a grant from the Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP) Sustainable Agriculture Program. This funding source was responsible for the Coordinator's salary, travel and all expenses associated with setting up demonstration sites as well as educational programs and publications for the nursery industry.

The Coordinator was responsible for administering all aspects of the project. This included the hiring and supervision of the program scout, soliciting participation in the full and partial IPM scouting programs, organization, registration and delivery of monthly twilight seminars during the growing season as well as a two-day winter workshop on pest management, pest reporting to the WDATCP's Cooperative Pest Survey Bulletin, submitting regular articles to the Wisconsin Nurserymen's Association monthly publication, The Green Side Up as well as the development of a scout training manual and the Woody Ornamental Pest Control Guide.

Additional sources of funding for the project included a per acre charge which was allocated to cover the expenses associated with scouting. This charge was assessed to all growers participating in the Full IPM program whereby the program scout monitored enrolled nursery stock on a biweekly basis beginning in mid-May through late August. Surveys distributed to the participating nurseries at the end of the first field season indicated they would pay as much as $30 per acre for the service provided.

SCOUTING PROGRAM OPERATION

Because early pest detection is critical to the implementation of a successful IPM program, a scouting service was offered to all nurseries in the demonstration area in southeastern Wisconsin. During the first year of the scouting program, the scout monitored nursery stock on a weekly basis. This frequency was decreased to biweekly since it was determined that the changes in pest populations over a seven day period were relatively insignificant. Follow-up spot checks were made between regularly scheduled visits as needed to observe pest population dynamics.

The scouting procedure was primarily visual with some use of pheromone traps as necessary. Because most nurseries contained many different species of plant material, it was necessary to examine a sample of each species in each field. Through the use of the key plant and key pest concept as well as phenology, it was possible to reduce the need for the scout to examine every plant species at each visit. By tracking the development of pests through degree day accumulations and indicator plant events, we were able to estimate which insect pests had reached an injurious stage in development. In a single day, the scout could be expected to monitor approximately 30 acres. This number may increase if there are large areas of a limited number of species, such as conifer

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[1]Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993

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transplants designated for Christmas Tree production.

Prior to each scouting season, a brochure describing the services offered was sent to every licensed nursery in the demonstration area. This list of nurseries was obtained from a database at the WDATCP State Nursery Inspector's office. A close working arrangement was upheld between the State Nursery Inspector and the Project Coordinator throughout the duration of the program since a similar interest, that of maintaining the highest quality of nursery stock possible, was the mission of both.

During the first year, six nurseries totalling 58 acres, enrolled in the program. In 1992 the number rose to nine nurseries and 115 acres; while during the third year, although two additional nurseries were added to the program, the acreage per nursery dropped. Financial constraints imposed by the struggling economy were suspected to be the cause.

The Full IPM Program was designed to target nurseries between 5 and 50 acres in size. It was not cost effective from a nursery standpoint to enroll large acreages in the program. Likewise, it was not cost effective from a program standpoint to scout very small acreages unless they were in close proximity to other enrolled nurseries.

In 1992, a partial IPM program was created whereby existing nursery employees were trained to do their own scouting. Nursery employees would monitor their stock on a biweekly basis and a report was submitted to the IPM Coordinator. Five nurseries, totalling over 700 acres, participated in this program. This project was less successful than the Full IPM program due to a lack of reporting by many of the nurseries in the program.

At the beginning of the season, the Coordinator visited each participating nursery to obtain a history from the nursery operator. Information derived from this history included the length of time in the industry, planting dates, history of the field prior to planting, soil type and soil test results, drainage, historically significant insect pest problems and their treatment, historically significant diseases as well as treatments and problem weeds. During this visit the Coordinator also presented a contract to the nursery owner for their signature. The contract specifically described the location of the stock to be monitored as well as the monitoring period.

The scout's report contained information on the quality of the stock inspected as well as any pests present. Insects, diseases and plant nutrition were the primary components of the program. A three-ply carbonless form was developed which provided information to the grower on the pest identified, its stage of development, damage site and severity, abundance of the infestation and distribution throughout the planting. Temperature, weather conditions, including wind speed, and pesticide applications were also recorded. A copy of the report was left with the nursery manager upon completion of each visit. Information was discussed as needed. A second copy of the report was given to the county horticultural extension agent for pest management recommendations. No control recommendations were made by the scout. The third copy was kept on file with the Coordinator for reference at later scouting visits.

Periodically throughout the season, the Cooperator would visit the enrolled nurseries. This was primarily to answer any questions the nursery operator may have as well as discuss any concerns regarding the scout's performance. At the end of the season, a written summary was compiled by the Coordinator for each participating nursery. The report included a listing of each pest identified and future recommendations for long-term management of the problem.

PEST FINDINGS AND PEST MANAGEMENT PRACTICES

In 1992, a survey was sent to 100 growers of coniferous and deciduous nursery stock to determine their pesticide use practices. The project was a joint effort between the Nursery IPM Coordinator, the Wisconsin Agricultural Statistics Service and the Wisconsin Nurserymen's Association. Funding for the project was made available through a grant from the National Pesticide Impact and Assessment Program.

The results of the survey were interesting and somewhat unexpected. When asked what the top ten pests of nursery stock were, growers responded that weeds, deer, rabbits, aphids and eastern tent caterpillars were their top five problems both in terms of abundance and economic impact. However, in discussions with

various nursery operators as well as observations made by the scout, it appeared that verticillium wilt; annual foliage-feeding insects such as plant bugs, leafhoppers, aphids and leafminers; and foliar pathogens such as apple scab and anthracnose were their main concerns. One explanation for such a discrepancy is that prior to the nursery IPM program, symptoms of problems such as verticillium wilt were unknown to the industry whereas weeds and deer damage were readily apparent and identifiable. Through educational programs, the industry has become more aware of some of the subtle problems which, preceding the nursery IPM program, were unrecognized as being related to diseases and insect pests.

Other topics polled in the survey include the current usage of non-chemical management practices. Over 90% of all respondents indicated that they used at least one type of non-chemical pest management strategy. Response to a question regarding the number of acres treated with a specific active ingredient disclosed that herbicides are most widely used in the surveyed population.

Another component of the Nursery IPM Program was the introduction of the use of phenology in determining the proper timing of pesticide applications, particularly in the case of insect pest management, has reduced pesticide use in many nurseries. However, there are still nurseries which exist in Wisconsin that espouse the idea that it is appropriate to treat all nursery stock with a broad-spectrum insecticide to control all insects which may be present at a given period. For the majority, however, spot treatments at the most susceptible stage in the insect's development has become the rule.

Weekly reports in the WDATCP Cooperative Pest Survey Bulletin alert growers throughout the state to degree day accumulations and insect development. Recommendations were made for the application of pest management practices based on this phenological information. The reports were brief and concise and fit readily into the busy schedule of the field operators.

The regular availability of educational programs, which prior to the inception of the Nursery IPM Program were virtually non-existent, has improved growers' pest identification skills. Subsequently, this has reduced the number of unnecessary pesticide applications made. During the summer twilight seminars, growers were offered an opportunity to share information with each other. This may have been as important as the information presented by the evening's speaker. Also, tours of host nurseries afforded participants a first-hand view of some of these ideas in practice. A case in point was illustrated by the nursery which successfully established a rye cover crop. Participants at that evening's program were able to question the nursery owner about what variety of rye was planted, where the grower purchased the seed, the cost of the seed and specific planting instructions such as what equipment was needed and the seeding rate. Several participants left the meeting with a much clearer grasp of the concept of living mulch. They are now in a better position to present the idea to their supervisors and/or coworkers for consideration.

EDUCATIONAL PROGRAMS

In addition to the scouting and pest reporting aspect of the Nursery IPM Program, a strong educational program was also developed. This consisted of monthly twilight seminars during the summer, a two-day pest management workshop in February, monthly articles on pests of woody landscape plants in the Wisconsin Nurserymen's publication, the Green Side Up, the development of a scouting manual and the Woody Ornamental Pest Control Guide as well as increased coverage of pests in the weekly WDATCP Cooperative Pest Survey Bulletin.

The Nursery IPM Twilight Seminars were designed to take an informal, hands-on approach to pest problems and other issues related to pest management in a nursery setting. Nurseries throughout the demonstration area volunteered to host these programs. Speakers were contacted to discuss issues related to pest identification and management. There was no preregistration necessary and the seminars were free of charge. Attendance was not limited to people associated with the nursery industry. After the first meeting, arborists, landscapers, grounds maintenance personnel and municipal workers also began to attend because the programs had a reputation of presenting valuable information for anyone concerned

with the culture and care of woody landscape plants.

Some of the topics discussed include insect identification and management, disease identification and management, weed identification, non-chemical alternatives to weed management, plant nutrition, new cultivars, living mulch for weed suppression, pesticide regulations and worker protection standards, regulated pests in Wisconsin and a hands-on display of the effects of cultural practices on the tree root system.

Alternative weed management practices were presented at one more than one seminar. Alternative practices include the use of a living mulch or cultivation between the rows in lieu of broadcast herbicide applications. This will reduce the amount of herbicide used to only a two-foot band within the row, while the remaining 10-12 feet between rows remains untreated. When compared to traditional broadcast herbicide treatments, herbicide banding does not present an economic savings. On the contrary, nurseries which practice clean cultivation have actually increased their cost by approximately $150/acre. The benefit from the standpoint of surface and groundwater quality is great and this tends to be the driving force behind the continuation of this practice. However, one must also consider the impact of clean cultivation on soil erosion.

A living mulch or cover crop may offer an alternative to traditional chemical weed management which provides both a reduction in surface and groundwater contamination by chemical herbicides as well as a reduction in the amount of erosion. In Wisconsin, the nursery industry is divided on their opinion on living mulch. The benefits have already been presented, now the costs must be weighed. The greatest concern lies in the competition between the cover and the desirable stock for nutrients and water. Preliminary research indicates there may be as much as a 10-20% reduction in caliper size when a living mulch is used. Other concerns relate to the potential increase in pest populations depending upon the mulch chosen. The potential for favorable rodent nesting sites was also a concern. At this time, there are nurseries which are strongly in favor of implementing a living mulch system. Demonstrations at these nurseries, through the Nursery IPM Program, have already been responsible for convincing some skeptical growers of this practice.

A more in-depth treatment of the pest problems associated with woody ornamental culture was offered at a two-day winter pest management workshop. The program was presented in both 1992 and 1993 and is expected to continue annually. During the first year, we offered both basic and more advanced topics to the participants. Basic insect taxonomy and plant pathology were offered to bring all participants to an equal level of understanding. From there, the program advanced to discuss some of the specific disease and insect pests of coniferous and deciduous stock. Other topics included nutrient deficiency and toxicity symptoms and recommendations as well as nutrient management. Also, an introduction to the symptoms of abiotic or environmental disorders and vertebrate pest damage was presented.

Because many people attended the program in 1992, the 1993 workshop was designed to be two one-day seminars with the first day covering the same material as the 1992 program and the second day being devoted to in-depth studies of nutrient and pest problems. This allowed participants to enroll in either day depending on their knowledge base. Participants were also allowed to enroll in both days if desired.

Attendance for both pest management workshops was excellent - the upper limit was reached both years and a waiting list was created. Some of the comments from participants indicated that the programs were very informative. They would like to see the programs continued and would like them to concentrate on specific pest problems and promote discussions in these areas. The use of slides which depicted field symptoms was beneficial and their future use encouraged. On the negative side, participants felt that too much time was spent on the presentation of microscopic identification of fungi and too many graphs and charts were used by some speakers.

The project Coordinator maintained a column in the Wisconsin Nurserymen Association's monthly publication, the Green Side Up. Each month a particular pest or topic related to integrated pest management was discussed. Each pest-related article included coverage of the damage symptoms caused by the pest, identifying characteristics of insects, life

cycles or disease cycles when appropriate, scouting tips and management strategies.

PEST REPORTING PROJECT

With the advent of the Nursery IPM Program, increased coverage of the pests of woody landscape plants appeared in the WDATCP Cooperative Pest Survey Bulletin. Sources of information on pest sightings in Wisconsin included the program scout's reports and the state nursery inspectors' reports. During the second year, nurseries in the partial IPM program who were responsible for their own scouting also provided pest reports. In addition, a strong cooperator network was developed and cooperators from throughout the state provided pest reports.

During the second year, pest predictions were also offered in the Cooperative Pest Survey Bulletin. A weather network was utilized with the assistance of the Extension agricultural meteorologist. Degree-day data was collected from several sights statewide and updated daily. Subscribers to the University of Wisconsin's WISPLAN weather network were able to access up-to-date weather information to aid them in pest management decisions. For the majority of nursery operators who did not subscribe to WISPLAN, degree-day information and pest predictions were provided weekly in the Cooperative Pest Survey Bulletin. This offered growers a more timely source of pest information. Reports of pest sightings may be 10-14 days old by the time the nursery operator receives the information. Often this is too late to act. However, now growers are alert to pest outbreaks before they occur.

Overall the Nursery IPM initiative in Wisconsin has been well received. During the remainder of 1993, the project will be turned over to various agencies and individuals outside of the University of Wisconsin. In particular the Wisconsin Nurserymen's Association and the Wisconsin Department of Agriculture, Trade and Consumer Protection will be responsible for the continuation of many aspects of the program. It is expected that the Nursery IPM Program will be continued for a long time to come and that the nursery industry in the state will continue to reap the benefits of this initiative.

Soil Moisture and Fusarium Root Rot of White Pine Seedlings[1]

Jennifer Juzwik, Peter J. Menes, and David J. Rugg[2]

Abstract – Field and controlled environment studies were conducted to determine the influence of soil moisture on the development and severity of Fusarium root rot of white pine seedlings grown in sandy loam soil. During the 2+0 year in a Wisconsin nursery field, disease levels were significantly higher in two outer bed-rows closest to the irrigation line than beds closer to the center of the field. Soil moisture levels were also significantly higher in the outer bed-rows. Higher disease levels were positively correlated with wetter soils, and were observed in saturated and dry soil treatments compared to field capacity treatments in white pine seedlings grown in soil artificially infested with *Fusarium oxysporum*, untreated field soil, and pasteurized soil in leach tubes in a growth room study. Results suggest that prolonged exposure of white pine to saturated or dry soil conditions promotes Fusarium root rot. Options for managing soil moisture in forest nurseries are discussed.

INTRODUCTION

Soil moisture plays a major role in incidence, development and control of forest tree nursery disease and insect problems. According to Sutherland and Anderson (1980) excess soil moisture favors damping-off and root rot, particularly those caused by water molds (*Pythium* and *Phytophthora*), and is a common problem in bareroot nurseries with irrigation systems. Other types of damping-off and root pathogens such as *Rhizoctonia* are favored by moisture deficient soils.

Soil texture (size of soil particles) greatly influences the moisture holding capacity of soil. The ideal nursery soil is a sandy loam that contains 15 - 20% silt and clay particles and 75 - 80% sand (Wilde, 1958). Ideally, nursery soils should be well drained.

In general, Fusarium diseases are more important in dry than wet soil conditions, although exceptions do exist (Cook and Papendick, 1972). Multiplication and survival of Fusaria are favored in sandy soils which are better drained, hold less water and dry faster than clays. Onset and severity of Fusarium diseases of winter wheat in the Pacific Northwest are favored by low plant water potentials (< -32 to -35 bars) (Cook, 1981). Susceptibility of sugar pine to Fusarium hypocotyl rot, caused by *Fusarium oxysporum*, was not affected, however, by plant water deficits of the magnitude recorded in a nursery field (Brownell and Schneider, 1985). Root necrosis of 2-year-old Douglas-fir seedlings due to *F. oxysporum* in Oregon occurred most commonly in wet areas of nursery beds (Hamm, et al., 1987). *Fusarium roseum* root rot of 1 and 2-year-old seedlings (white and loblolly pine, Douglas-fir, Norway spruce) was reportedly triggered by wet weather and poor drainage in a Delaware Nursery (Schwalm, 1972).

Root rot has been observed in white pine seedlings and transplants in bareroot nurseries with sandy loam soils in the north central states (USA) and in southern Ontario (Canada) for many years. Several *Fusarium* species obtained from diseased white pine seedlings from an Ontario and a Wisconsin nursery have recently been demonstrated to cause root rot (Ocamb and Juzwik, unpub.). *Fusarium* species are considered facultative parasites, i.e. they are able to grow saprophytically on non-living organic matter but are also able to cause disease in living plants. The most pronounced effects of water stress on disease development are evident with diseases caused by facultative parasites (Schoenweiss, 1978).

In 1989 we hypothesized that white pine root rot in northern nurseries was caused by *Fusarium*, and disease development was favored by soil moisture extremes. The objectives of our recent studies were to determine the influence of soil moisture and plant moisture stress on the development and severity of

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

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Fusarium root rot of white pine seedlings in nursery field and controlled environment conditions. Preliminary results of those investigations are presented here.

MATERIALS AND METHODS

Field Study

Study site

The field trial was conducted between 1989 and 1991 in one-half of a nursery section (165 m x 7.6 m) at Wilson Nursery, Boscobel, WI. Soils in this section were naturally infested with *Fusarium* spp.. Mean soil-borne population of *Fusarium* spp. was 2206 colony forming units(cfu)/g dry soil during 1991. The soil in the section is a sandy loam with pH range of 5.4 - 6.0, maximum water holding capacity of 21%, an average bulk density of 1.21 g/cm^3, and an organic content of 1 - 2 %. Irrigation water is applied through overhead, fixed pipes on permanant risers with oscillating nozzles.

Crop history

The section had a history of root rot in previous white pine crops. The section was fumigated with methyl bromide - chloropicrin (MC-33) in mid-August 1989, following incorporation of a sudan cover crop. Four beds were formed and white pine seed sown in early October 1989. Stand counts and seedling assessments were made through the 1+0 year prior to commencement of this study. Root disease was first apparent in the crop in September 1990.

Experimental design

The half section was divided into three blocks (55 m x 7.6 m). Two 1.1 m^2 permanent sampling plots were established in each of the four bed-rows in each block to give a randomized complete block design.

Monitoring and assessment

The total number of seedlings (living + dead) was determined for each plot in mid-May, late July and mid-October of the 2 + 0 year. Shoots of dead seedlings were cut at the ground line after counting. Ten living seedlings were randomly selected and removed from each plot on each sampling date for root assessment. The seedlings were stored in plastic bags at 4° C until processed. Daily mean soil matric potentials (smp) were determined at 10 cm depth in plot soils during the 2 + 0 growing season using electrical resistance (gypsum) blocks and electronic dataloggers (Campbell Scientific Inc., Logan, UT).

In the laboratory, seedling roots were carefully washed and the root system rated for evidence of root rot: 1 = apparently healthy; 2 = over 50% length of one secondary root was necrotic; 3 = root necrosis in lower third of primary root or > 50% of two or more secondary roots necrotic; 4 = root necrosis in middle third of primary root; 5 = root necrosis in upper third of primary root or total root system dying or dead. Fungal isolations were also made from the edge of necrotic root tissue of affected seedlings. Excised tissue was placed on a *Fusarium* selective medium (Nash and Snyder, 1962), petri dishes incubated for 14 - 21 days at 24 C, and then examined for *Fusarium* spp..

Data analyses

Disease data were summarized categorically by disease incidence and severity rating for each sampling date and cumulatively. Daily soil matric potential readings were classified in the following categories: wet = > -0.25 bars; upper field capacity = -0.25 to -0.40 bars; lower field capacity -0.40 to -0.65 bars; and dry < -0.65 bars. The number of days that readings occurred in the different categories was tabulated by month, by half of growing season, and cumulatively. Disease and soil moisture data were analyzed using standard contingency table methods (Fienberg, 1980). Log linear modelling of treatment effects was used to further understand the contingency tables used.

Controlled Environment Study

Experimental design and soil treatments

A factorial design involving three soil moisture treatments and three soil fungal treatments was used for the controlled environment study. Sandy loam soil (pH = 5.4; maximum water-holding capacity = 23%; organic content of 1 - 2%) was obtained from a white pine field at St. Williams Nursery, St. Williams, Ontario, Canada. Following mixing, three quarters of the soil was divided into 2 kg batches and autoclaved for 50 minutes at 1 kg/cm^2 (15 psi) and 121° C; the remaining quarter was not treated and served as the non-pasteurized field soil treatment.

Ground inoculum of a pathogenic isolate of *Fusarium oxysporum* f.sp. *pini* produced as an inoculum cake (Miles and Wilcoxson, 1984) was added to one-third of the pasteurized soil (1 g inoculum/kg soil) and mixed well. Another third of the pasteurized soil was designated as sterile control soil. Over 100 20-cm-long leach tubes (Stuewe and Sons Inc., Corvallis, OR) were filled to 13 cm height with the different soils. All tubes were then topped to 18 cm height with the remaining pasteurized soil.

Growing conditions and moisture treatments

Eastern white pine seeds were surface sterilized in 10% NaOCl for 25 minutes, rinsed in running water for 24 hours, and stratified for 60 days at 4°C. Seeds were sown in the pasteurized layers of all leach tubes, covered with pasteurized silica grit, and the soil watered to saturation. The trays with the tubes were moved to a walk-in growth room set for 20 C day/18 C night temperature, 18 hour photoperiod, and 60-70% relative humidity. Three weeks after sowing, the germinated seedlings were fertilized with a 11-41-8 fertilizer at 75 ppm nitrogen. Subsequently, seedlings were fertilized weekly at 100 ppm nitrogen using a 20-8-20 fertilizer. The seedlings were grown for 7 weeks (after sowing) before the following soil moisture treatments commenced: 1) saturated —watered after 2-4 days when the soil moisture content (smc) reached 17% or smp < -0.1 bar; 2) field capacity — watered after 4-6 days when the smc was around 11% or smp between - 0.1 and -0.3 bars; and 3) dry — watered after 11-18 days when smc was around 5%. Watering regimes were based on mean tube weights that were determined to correlate well with gravimetric determinations of smc. The oven dry weight of the soil (105° C for 48 hours) was the reference weight used for calculating smc (Thompson and Troeh, 1973). The soil moisture treatments continued through two drying cycles of the dry treatment.

Assessment and sample processing

Soil and plants were removed from 30 leach tubes per treatment following the soil moisture treatment period. Soil moisture content was determined gravimetrically to verify moisture level achieved. Root systems of all seedlings were washed, examined, and rated for evidence of root rot per method described in field study section.

Data analyses

Root rot data were summarized categorically by disease incidence and severity rating. The data were analyzed using standard contingency table methods (Fienberg, 1980).

RESULTS

Field Studies

The total number of seedlings (living + dead) in each plot in May 1991 of the 2 + 0 year in the Wisconsin nursery field ranged from 158 to 471 per 1.1 m^2 plot with a mean of 321. Cumulative seedling mortality occurring within the plots between May and October 1991 averaged 7.5% (SE=1.4%). Seedling mortality

Table 1. Average number of days bed-row soils were determined to be in different soil moisture categories during 2+0 growing season in the Wisconsin nursery field

	Soil moisture category[b]			
Bed-row no.[a]	wet	upper field capacity	lower field capacity	dry
1	71	59	8	4
2	66	63	9	4
3	49	60	15	18
4	52	60	13	17

[a] Six monitoring plots per bed-row.
[b] Wet = > -0.25 bars; upper field capacity = -0.25 to -0.40 bars; lower field capacity = -0.40 to -0.65 bars; and dry = < -0.65 bars.

varied among the bed-rows ($P < 0.0001$), and was related to bed-row location. The highest mortality occurred in the two bed-rows nearest the irrigation line (10.4% for bed-rows 1 and 2, compared to 3.5% in 3 and 4; $P < 0.0001$).

By the end of the 2+0 year, average root rot incidence was 30.4% (SE=4.3%). *Fusarium* spp. were recovered from necrotic areas on primary and secondary roots of 72% of the seedlings visually assessed to have root rot. Significant effects of location on disease level appeared by July 1991, and became more pronounced by October 1991. In October, incidences were highest in the two bed-rows nearest the irrigation line (bed-row 1 = 50% and 2 = 33.3%) compared to the more distant bed-rows (18.3% and 20% in bed-rows 3 and 4, respectively) ($P = 0.0002$). Disease severity also appeared to be highest in bed-rows 1 and 2 in the July and the October 1991 assessments.

Mean daily soil matric potentials (smp) were determined between 20 April and 8 October 1991 with electrical resistance blocks. No differences in monthly mean soil matric potentials among plots were apparent for April, May, September, and October. Apparent differences were, however, noted in mean monthly readings for June, July and August. Based on cumulative readings for the growing season, soils in bed-rows 1 and 2 were saturated (smp > - .25 bars) for a significantly greater number of days than those in bed-rows 3 and 4 (Table 1) ($P < 0.001$). Conversely, soil in bed-rows 3 and 4 were dry (smp < - 0.65 bars) for a significantly greater number of days than the other 2 bed-rows ($P < 0.001$)

We are conducting regression analyses using soil matric potentials and root disease levels to better define the relationship between the two variables. Preliminary results show that higher disease incidence is positively correlated with less negative soil matric potentials (wetter soil) and lower incidence with more negative soil matric potentials (drier soil) over the range of soil moisture conditions encountered in the field (Fig. 1).

Controlled Environment Study

Mean *Fusarium* spp. levels expressed as cfu/g dry soil in the container soils in the growth room experiment based on an assay of 15 tubes/soil treatment were: 44 for pasteurized control treatment; 201,591 for the pasteurized + *F. oxysporum* soil; and 2,146 for the non-pasteurized field soil

Table 2. Number of white pine seedlings that exhibited root rot at the end of controlled environment experiment on disease-soil moisture interaction

			Severity rating [b]			
Soil treatment	**Moisture treatment**	**DI** [a]	**1**	**2**	**3**	**>3**
pasteurized	saturated	9	21	4	2	3
pasteurized	field capacity	5	25	2	2	1
pasteurized	dry	7	23	2	4	1
pasteurized + fungus [c]	saturated	15	15	5	10	0
pasteurized + fungus	field capacity	8	22	3	4	1
pasteurized + fungus	dry	13	17	5	7	1
non-pasteurized field	saturated	14	16	4	8	2
non-pasteurized field	field capacity	6	24	2	4	0
non-pasteurized field	dry	11	19	4	7	0

[a]Number of affected seedlings per 30 examined
[b]The higher the rating the more severe the root rot. See materials & methods section for description of ratings.
[c]Pathogenic isolate of *Fusarium oxysporum* f.sp. *pini*

treatments. Minimum soil moisture content reached during the drying cycles for each moisture treatment over the 33 day treatment period were: 17% with 14 drying cycles for saturated; 11% with 7 drying cycles for field capacity; and < 5.5% with 2 drying cycles.

Elevated disease incidence and severity levels were observed for seedlings in saturated and dry soil treatments compared to field capacity in all soil treatments (Table 2). Preliminary analyses on disease incidence data revealed a highly significant effect of moisture treatment on seedling disease incidence ($P = 0.009$); soil treatment effect on disease incidence was not as pronounced ($P = 0.067$).

CONCLUSIONS

Preliminary results of the field study suggest that soils that are saturated over a large number of days during the growing season promote greater Fusarium root rot development in white pine seedlings than soils that apparently dry out reasonably quickly after irrigation or rainfall. Saturated soil conditions were observed in bed-rows with the highest disease levels for > 46% of the days monitored in the 2+0 year while dry soil conditions were more common (25% of monitored days) in bed-rows with lowest disease levels. Dry soil conditions experienced during the growing season did not appear to be severe or long enough in duration to increase root rot development. Ideally, nursery soils should be maintained at field capacity for optimal growth and vigor. The cause of the prolonged saturated soil in two bed-rows of the field study is not known. Impeded drainage due to compacted soil layers is suspected. However, irrigation patterns and practices also need to be evaluated.

Preliminary results of controlled environment studies showed both saturated (≥ 17% swc) and dry (< 5.5%) soil conditions favored Fusarium root rot development compared to field capacity conditions (11 - 17% swc) for a sandy loam soil.

Management Implications

Either excesses or deficits of soil water may cause significantly higher seedling root rot in lighter or heavier soils in forest nurseries, depending upon the pathogens involved. Considerable control over root disease may be achieved through appropriate soil management actions or practices without chemical use. Actions suggested by Cooley, et al. (1985) for managing Phytophthora root rot of conifers in the Pacific Northwest include improving drainage and tailoring irrigation practices to minimize disease. Drainage can be improved in fields with histories of root rot and excess soil moisture by installing a subsurface drainage system, using ditches to remove surface water, sloping fields (through grading) toward roads or other noncultivated areas, subsoilling to break up compacted soil layers, and elevating beds in the fields. Modification of irrigation systems or practices may also provide considerable control of root diseases in forest nurseries. For soil-borne diseases favored by excess moisture, practices may be modified to avoid saturating soils continually or soils over extended periods of time, to avoid overirrigation, and theoretically to avoid alternating drying and saturating of soil (i.e. try to maintain field capacity conditions as much as possible). For situations favored by soil moisture deficit, adjust timing, placement, and/or amount of water delivered to fields by the irrigation system to promote optimal seedling growth. In both excess and deficit soil moisture situations, seasonal monitoring and maintenance of irrigation equipment is required to ensure optimal irrigation patterns which deliver amounts of water appropriate for the crop growing stage and existing weather conditions.

ACKNOWLEDGEMENTS

Partial support for this research was provided by an Ontario Renewable Resources Research Grant, Ontario Ministry of Natural Resources, and by the Wisconsin Department of Natural Resources. The authors thank K. Stolhammer, C. Ocamb, J. Rykhus, G. Sanguins, and S. Watson for technical assistance. The field site was provided by the Wisconsin Department of Natural Resources.

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Alternative Technologies for Management of Soil-borne Diseases in Bareroot Forest Nurseries in the United States[1]

R. L. James, D. M. Hildebrand, S. J. Frankel, M. M. Cram and J. G. O'Brien[2]

Abstract — Many forest nurseries producing bareroot seedlings in the United States rely on soil fumigation with methyl bromide and other chemicals to control soil-borne diseases. Methyl bromide production and importation will be phased out by the U.S. Environmental Protection Agency by the year 2000. Growers need alternative production technologies to grow high quality seedlings without fumigation because substitute fumigants are undesirable due to environmental and human health hazards. The Forest Pest Management branch of the USDA Forest Service recently instituted field trials at several U. S. nurseries to evaluate alternative cropping regimes and determine their effects on soil-borne diseases. Various organic amendments, fallow periods, cultivation regimes, and cover crops will be compared to methyl bromide fumigation. Additional studies will evaluate beneficial microorganisms and suppressive soils, develop accurate sampling techniques for differentiating pathogenic *F. oxysporum* populations, karyotype *Fusarium* isolates, and develop ELISA assays for detection and quantification of plant pathogenic *Cylindrocladium* and *Macrophomina* spp.

INTRODUCTION

Most U.S. bareroot nurseries rely on chemical fumigation to reduce levels of soil-borne pathogenic fungi, nematodes, weeds, and insects. Soils are routinely fumigated every 2-3 years at approximately 90% of U.S. bareroot nurseries (Fraedrich 1993). In the northern and western portions of the United States, 80% of the nurseries fumigate soil, whereas fumigation occurs at 96% of the southern nurseries. Many nurseries fumigate soil before each seedling crop, except in the southern United States where soils are often fumigated before every other or every third crop. However, each seedling crop produced in the southern United States usually requires only one year, whereas crops in the western and northern states takes 2-3 years.

Methyl bromide, applied with chloropicrin, is used by almost all nurseries that fumigate their soil (Fraedrich 1993; James 1989). Although other chemical fumigants are available (table 1), most growers believe existing alternatives are not as effective as methyl bromide formulations. Dazomet (Basamid®) fumigant has been tested at half of the nurseries that fumigate their soil, but results show it is often less effective than methyl bromide (Fraedrich 1993).

Methyl bromide is widely used as a soil fumigant to produce strawberries, peppers, tomatoes, tobacco, citrus and ornamentals (NAPIAP 1993). It is also used for post harvest treatment of fruits and vegetables, quarantine treatments, and structural fumigation. The 1991 Montreal Protocol Assessment alledged that methyl bromide was in a category of chemicals that depletes stratospheric ozone (NAPIAP 1993). In response to this assessment, the United States Environmental Protection Agency (EPA) under the Clean Air Act, called for phase out of production and importation of methyl bromide by the year 2000. Although there are many uncertainties regarding methyl bromide's relationship to ozone depletion, the phaseout is progressing. Annual monetary losses resulting from a total ban of methyl bromide use in U.S. agriculture are estimated at $1.3 to 1.5 billion (NAPIAP 1993). The share of these losses attributed to forest tree nurseries amounts to $35 million/year.

Many nursery growers desire alternatives to chemical fumigation because of high costs of fumigation, health risks to nursery workers, visitors, neighbors and wildlife, and a desire to reduce environmental contamination, especially ground water supplies. Growers want an integrated pest management (IPM) approach for dealing with soil-borne diseases, weeds, and insect pests (Campbell 1991; James and others 1990; Raupp and Cornell 1988). Implicit in IPM is a formal decision-making process that considers pest populations and their impacts on hosts, and weighs the effectiveness of con-

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

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trol methods against their impacts on economics, human health, and the environment. This approach requires much more information on biological interactions of soil microorganisms and a reliable system for disease prediction and monitoring of pathogen populations. Because fumigation with non-selective biocides kills all soil organisms, knowledge of the dynamics and interactions of soil micro-organisms have not been critical and little is currently known about them.

To prepare for the loss of methyl bromide, the Forest Pest Management branch of the U. S. Forest Service initiated alternatives to fumigation trials in four western states (California, Oregon, Washington, Idaho), Minnesota and Florida. This paper outlines the project's background, methods and expected outcomes.

RESEARCH BASIS

Although most U.S. forest nurseries routinely fumigate their soil, several western nurseries produce high-quality seedlings without fumigation. Methyl bromide fumigation is prohibited in Canada, so bareroot nurseries there have never fumigated. Yet they still produce high-quality seedlings. These precedents were examined to provide the basis for conversion from a reliance on fumigation to cultural and biological pest management methods.

Effects of *Brassica* cover crops, sawdust amendments, and fallowing with periodic cultivation on production of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings have been evaluated in several nurseries in Oregon and Washington (Stone 1993). This research into alternative cropping regimes indicates that quality conifer seedlings can be grown without soil fumigation by using bare fallow and cultivation. In this trial and others, cover crops stimulated increases in populations of potentially pathogenic organisms and may be detrimental to seedling health (Patrick and Toussoun 1970; Stone 1993).

Research in agricultural systems shows that suppressive soils (those which may contain pathogens, but within which no disease occurs) may be induced by cultural manipulations including addition of organic amendments to soil (Toussoun 1975,; Sinclair and others 1975; Schisler and Linderman 1989). In China, Japan, and other parts of the Orient, organic amendments have been used in agriculture with beneficial effects for many years (Hoitink and Fahy 1986; Huang and Kuhlman 1991; Kelman and Cook 1977). Through cover crop incorporation, and/or organic soil amendment, microorganisms antagonistic toward or competitive with soil-borne pathogens may be stimulated, resulting in lower disease levels (Baker and Cook 1974; Ramirez-Villapudua and Munnecke 1988). These soil treatments create a "biological balance" where pathogenic microorganism populations are kept low while beneficial competitors and antagonists are increased (Danielson and Davey 1969; James 1989; Vaartaja 1967). It may take several cropping cycles to achieve the desired "biological balance" of microorganisms, but once established, such communities are quite stable and should remain so indefinitely unless extensive disturbances occur, such as fumigation (James 1989).

Biological control has reduced soil-borne pathogens in agricultural systems and has great

Table 1 – Non-methyl bromide chemical fumigants for use in forest tree nurseries and their characteristic target organisms (from Andersen and Lee-Bapty 1992).

Fumigant Formulation	Trade Name	Target Organisms
dazomet	Basamid®	Soil-borne pathogens, weeds, and insects
metam-sodium	Vapam® Busan ®	Soil-borne pathogens, nematodes, weeds, and insects
77.9% 1, 3 dicholopropene 16.5% chloropicrin	Telone C-17 ®	Soil-borne pathogens and nematodes
1, 3 dichloropropene	Telone II ®	Soil-borne nematodes
20% methyl iso-thiocyanate 40% dichloropropenes and dichloropropanes 10% inert	Vorlex®	Soil-borne pathogens, weeds. insects and nematodes
Chloropicrin	None	Soil-borne pathogens and nematodes

potential in forest tree nurseries (Baker and Cook 1974; Campbell 1989; Papavizas 1985; Van Wyk and others 1988). Antagonistic and competitive fungi and bacteria provide control of many soil-borne pathogens (Baker and Cook 1974; Elad and Baker 1985; Sivan and Chet 1989). Since commercial biocontrol agents have been developed for agricultural crops other than forest tree seedlings, these agents need to be critically evaluated for efficacy in forest nurseries and integrated with other practices designed to enhance soil suppressiveness. Screening of potential biocontrol agents obtained from forest nursery soils is also needed to determine if nursery specific or region-wide biocontrol agents may be found.

Improvements in monitoring and detecting soil-borne pathogens are needed. Using current assay procedures, *Fusarium* and *Pythium* population levels have not been useful for predicting seedling disease development; there is often little or no relationship between soil population levels of *Fusarium* and *Pythium* and levels of disease on seedlings. This is primarily due to our inability to distinguish between pathogenic and non-pathogenic strains of these fungi. Pathogenic and non-pathogenic strains can be morphologically similar (Bloomberg 1966; Booth 1971) so total populations are not accurate disease predictors. Recently refined molecular techniques may be valuable for differentiating among fungal genera, species, and strains (Kerr 1987; Young 1990). Pulsed-field gel electrophoresis, polymerase chain reaction, random primed amplified DNA, and vegetative compatibility groupings will be used to measure genetic differences of fungi (Gordon and Okamota 1992; Puhalla 1985). These techniques will be adapted for use in assays to quickly differentiate pathogenic and non-pathogenic fungal strains within soil and infected plant material without having to resort to burdensome pathogenicity tests.

This project will answer four major questions:

1 Can alternative cropping techniques including bare fallow, cover crops, and soil amendments, be used to manage soil-borne diseases in high-volume production nurseries?

2 Can biocontrol techniques, including beneficial microorganisms and suppressive soils adequately control soil-borne diseases in bareroot forest nurseries?

3 Can recent developments in biotechnology be applied to genetically differentiate pathogenic and non-pathogenic populations of *F. oxysporum* Schlecht. in forest nursery soils and on seedling roots?

4 Can immunoassay techniques be developed for detecting *Cylindrocladium* and *Macrophomina* spp. which are as effective as existing cultural or other techniques of detection.

METHODS

In 1993, eight nurseries set up alternatives to fumigation trials in the western United States: three in California, one in Washington, and two each in Oregon and Idaho. One Florida nursery was included; nurseries in Minnesota, North Carolina and South Carolina will be added in 1994. The project will span four years to allow for bareroot seedling production in the western and northern regions: one year for pre-sowing treatments, two years for crop production, and one year for post-lifting analyses. In the southern region, crops are grown annually; therefore, several crop cycles are possible during this timeframe.

Field treatments tailored to each nursery are being tested. Locally available soil amendments, cover crops adapted to local growing conditions and available equipment will be used to create soil conditions that minimize damage from soil-borne organisms. Treatments include the following organic amendments: sawdust, sewage sludge, composed mushroom media, pine bark, yard waste, and pine needle mulches. Most nurseries will test bare fallowing with periodic cultivation because of its reported success in British Columbia and Oregon and Washington (Stone 1993). Standard chemical soil fumigation will be included for comparison. Treatments will be compared for seedling establishment, disease incidence and severity, seedling growth, and production of shippable seedlings per unit area.

Plots were set up using a complete randomized block design with buffer areas between treatments. Operational nursery procedures for fertilization, irrigation, and weed control are being used. One conifer sepecies of one seedlot will be sown into all treatments to reduce inter-seedlot variability.

Fusarium populations are being monitored and estimates of pathogenic species will be made for each treatment (proportion of the *Fusarium* population that consists of *F. oxysporum*). Soil samples will be processed by one laboratory to reduce variability in assay procedures. Several samples of forest soil will be evaluated for inherent suppressiveness to soil-borne pathogens through greenhouse screening followed by field testing.

Because of its wide geographic distribution and importance in forest nurseries (James and others 1990), *F. oxysporum* will be used for most of the detection protocols. Representative *Fusarium* isolates will be maintained and techniques developed to rapidly elucidate pathogenicity. Pathogenic strains and host range variabilities will be identified and evaluated using molecular techniques to determine the genetic component of pathogenicity. Vegetative compatibility grouping, pulsed-field gel electrophoresis, and polymerase chain reaction to amplify probes will be tested to determine their ability to distinguish pathogenic and non-pathogenic strains. Population genetics of F. oxysporum within selected nurseries will be elucidated and quick assay techniques developed for determining the proportion of pathogenic strains within a population.

For detection of *Cylindrocladium* and *Macrophomina*. enzyme-linked immunosorbent assays (ELISA) will be developed. The development and testing of ELISA kits will occur in three phases. In the first phase, antibody titers for the immunoassay will be produced from rabbits inoculated with antigens and Freund's complete adjuvant. Three types of testing will be conducted in the second phase: cross-reactivity with other common root pathogens and soil saprophytes, comparison studies with existing detection techniques for *Cylindrocladium* and *Macrophomina*, and determination of sensitivity of the immunoassays. In the final phase, ELISA detection kits will be field tested.

COOPERATORS

This project will include several cooperators from government, universities, and private research laboratories. A listing of cooperators is in Table 2.

EXPECTED PRODUCTS

At the conclusion of this project, the following will be available:

1 Customized recommendations of cultural and biological treatments for management of soil-borne diseases without chemical fumigation.

2 Protocols for differentiating pathogenic and non-pathogenic populations of

Table 2. Cooperators investigating alternative technologies for management of soil-borne diseases in bareroot forest nurseries in the United States.

USDA Forest Service
Forest Pest Management
Region 1 (Northern Region)
Region 6 (Pacific Northwest Region)
Region 5 (Pacific Southwest Region)
Region 8 (Southern Region)
Northeast Area - State and Private Foresty
Research
North Central Forest Experiment Station
Southeastern Forest Experiment Station
State Organizations
Florida Division of Forestry
California Department of Forestry
Oregon State Department of Forestry
Universities
Oregon State University
University of British Columbia
Clemson University
Private Laboratories
B. C. Research (Vancouver, British Columbia, Canada)
PENINSU-LAB (Poulsbo, Washington)

F. oxysporum and ELISA detection kits for *Cylindrocladium* and *Macrophomina.*

3 Information on the genetic makeup of *Fusarium,* nursery soil suppressiveness, and soil ecosystem interactions.

CONCLUSIONS

The transition from a reliance on chemical soil fumigation to growth regimes without fumigation will be difficult. Most cultural and biological techniques may have limited effectiveness and growers may have to accept higher than usual losses or lower seedling quality. Eventually, pest-caused losses should decline as soils become more suppressive (Toussoun 1975). Improved detection tools will aid in understanding soil ecosystems and allow pathologists to predict effects of cultural treatments on disease development, thereby enabling growers to minimize losses.

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Interactions Between Seedbed Mulches and Seedling Disease Development[1]

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Abstract – Seedbed mulches might be thought to have little influence on disease relationships in forest tree nurseries. In fact, mulches may serve as sources of pathogenic inoculum, or provide conditions that either favor or prevent the development of seedling diseases. This paper highlights aspects of mulch-disease interactions and summarizes a Florida study in which mulching provided useful control of *Rhizoctonia* seedling blight of longleaf pine (*Pinus palustris*). A basic understanding of the biology of soilborne pathogenic and beneficial microorganisms and the influence that cultural practices such as mulching may have on disease development is both needed and encouraged.

Mulching of seedbeds immediately after seed sowing has been and remains a common practice in the production of bare root seedlings in forest tree nurseries. A good mulch provides an important cover for newly sown seeds, enhances seedbed soil stability, facilitates seed germination via maintenance/retention of adequate soil moisture, and buffers seed and seedlings from extremes in soil surface temperatures. Organic mulches provide the added benefit of building or maintaining desirable levels of soil organic matter, which in turn enhance soil structure, water and nutrient relations, and soil microbiological interactions (Adams 1966, Bollen and Glennie 1961, Davey and Krause 1980, Mannering and Meyer 1963, Van Nierop and White 1958).

Although not commonly perceived as a contributor to disease development or a control for nursery seedling diseases, mulches may, depending upon a variety of factors, be either. In this paper we

1 highlight reports from the literature where mulches were known or believed to have influenced seedling diseases (esp. in forest tree nurseries)

2 allude to mechanisms involved in mulch-disease interactions

3 consider criteria for mulch selection with respect to disease relations, and

4 review a case history from a Florida forest nursery where mulching has been employed successfully for control of *Rhizoctonia* blight of longleaf pine (*Pinus palustris* Mill.).

INVOLVEMENT OF MULCHES IN NURSERY DISEASES: A LITERATURE PERSPECTIVE

Mulches as sources of inoculum.

The type and source of available mulching materials and their potential for carrying pathogenic organisms are issues that need to be considered when selecting a mulch for nursery seedbeds. Certain materials have a higher probability of being contaminated with pathogenic organisms than others (Bloomberg 1963, 1985, Hoitink *et al.* 1976, Schönhar 1968). For instance, the fungus *Sphaeropsis sapinea* (Fr). Dyko & Sutton can infect and sporulate on cones, needles, and branches of Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) and red pine (Pinus resinosa Ait.) (Sinclair *et al.* 1987), and one should avoid use of these materials as mulches where susceptible species are grown (Peterson and Nichols 1989). Sand and peat moss can carry pathogenic species of *Pythium* and *Fusarium* (Sutherland 1984), and warnings have been issued to Southern nursery managers about the potential for

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

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pine needles to carry *Fusarium* spp. and the charcoal root rot fungus, *Macrophomina phaseolina* (Tassi) Goid. (Cordell and Lantz, U.S.D.A. Forest Service, FIDM Letter to Southeastern Forest Nurserymen, February 29, 1980). Needles of some conifer species may carry needle cast fungi such as *Meria laricis* Vaill. and *Lophodermium* spp. and should be avoided where diseases caused by such fungi pose a hazard to seedling crops (Sutherland 1984, Staley and Nichols 1989).

Influence of mulches on disease development

In addition to the possibility of introducing pathogenic fungi into nurseries, certain types of organic matter may differentially favor the development of pathogenic and beneficial fungus populations. For example, Bloomberg (1963) found that species of *Trichoderma* predominated on hemlock sawdust, but species of *Alternaria* were favored by straw. *Trichoderma* spp. are generally believed to restrict the growth of pathogenic spp., but *Alternaria* spp. are regarded as pathogens in some situations. Table 1 provides an overview of some mulch-disease interactions on various seedling crops as reported in the literature. Note that the influence of mulches can be variable, sometimes promoting and sometimes preventing disease development. Mechanisms involved in such influences are myriad, often subtle, complex and may be biological, chemical, and/or physical in nature (Table 2).

Table 2. Some ways in which mulches may influence disease development.

Biologically	promote/suppress pathogen activity
	stimulate competitive/antagonistic microflora
Chemically	pH alterations
	nutrient relations
	direct phytotoxicity
	pesticidal (suppression)
Physically	soil stability
	temperature
	H_2O
	aeration
	flotation

Soil moisture and temperature relationships

Mulches influence soil temperature and soil moisture. Such

Table 1. Some examples of mulch-disease interactions on various seedling crops.

Mulch Material	Crop	Effect	Ref.
Sawdust	Longleaf Pine	Decreased D.O.[1] (Rhizoctonia)	Davis 1941
Sphagnum	-----	Decreased D.O.	Winters 1949
Coir Dust	Mahogany	Decreased D.O.	Barnard 1950
Doug-fir Sawdust	Strawberries	Increased Phytophthora	Vaughan et al. 1954
Various	Ginko	Decreased M. phaseolina	Fang et al. 1956
Sawdust/Wood Chips	-----	Increased Nematodes	Van Nierop & White 1958
"Dark" Sawdust	Douglas-Fir	Increased Heat Lesions	Salisbury & Long 1959
Pine Sawdust/Bark	Pinus sp.	Decreased D.O.	Vaartaja & Bumbieris 1965
Sawdust	Ginger	Decreased Root-Knot Nematodes	Colbran 1974
Redwood Bark/Sawdust	Red Fir & Douglas-Fir	Decreased Phoma Blight	Kliejunas et al. 1985
Hardwood Bark/Wood Chips	Longleaf Pine	Decreased Rhizoctonia	Gilly et al. 1985

[1] D.O. = damping-off

Table 3. Some factors to consider when selecting mulching materials for forest nursery seedlings.	
Availability	Cost
Timing	Rate
Material	natural/synthetic
	organic/inorganic
Age/Condition	fresh/aged/ composted
	chemistry (phyto-toxicity, C:N ratio)
Color	temperature relations
Texture	stability
	H2O relations
	aeration
Source/ Handling	contaminant/ pathogenic organisms
	beneficial/microorganisms

influences can indirectly influence the development of biotic diseases, either positively or negatively, depending on particular host-pathogen relationships. For example, Vaughan *et al.* (1954) found that increased soil moisture and reduced soil temperatures associated with the use of Douglas-fir sawdust mulch increased red-stele disease in strawberries caused by the water mold fungus, *Phytophthora fragariae* Hickman. In contrast, the use of mulches has been credited with the control of charcoal root rot on ginkgo (*Ginko biloba* L.) seedlings (Fang *et al.* 1956). In this instance, the use of a mulch on nursery beds maintained soil temperatures below those considered optimal (c. 32oC) for infection by the pathogen, *Macrophomina phaseolina.*

Alternatively, the influence of mulches on soil and/or soil surface temperatures can directly affect seedlings by causing or preventing abiotic injuries or "diseases". For example, dark colored mulches may absorb solar heat, and thereby increase the chances of heat injury (Barnard 1990, Boyce 1961, Peace, 1962). The use of light colored mulches, on the other hand, can reduce heat injury by reflecting insolation and dispersing heat. However, under certain circumstances, light colored or reflective mulches also may contribute to heat injury of seedlings. Richards (1970) found that the use of fiberglass and spruce needles as mulches could greatly increase temperatures immediately above seedbeds and that these elevated temperatures were damaging to white spruce [*Picea glauca* (Moench) Voss] and Norway spruce [*P. abies* (L.) Karst.].

Physical relationships

The ability of a mulch to act as a barrier against wind and rain and hold a soil in place can play a significant role in the prevention of some diseases. Kliejunas *et al.* (1985) reported that mulch composed of redwood bark and sawdust reduced soil splash, soil cone formation and the incidence of Phoma blight caused by *Phoma eupyrena* Sacc. in fir and Douglas-fir seedbeds in a California nursery. Soil splash that normally occurred during winter months led to soil cone formation around seedlings. This soil cover was believed to reduce seedling vigor and provide an environment favorable to disease development. The use of a mulch in Florida nurseries has produced a similar beneficial effect with regard to the development of *Rhizoctonia* blight of longleaf pine (see Case History below).

Chemical relationships

Chemicals that are naturally associated with certain types of organic matter (...mulches) can suppress growth and development of soilborne pathogens. Extracts from sawdust of *Pinus banksiana* Lamb., *Populus* spp. (Carlson and Belcher 1970), and hardwood bark compost (Kai 1990) can inhibit the growth of certain species of root-infecting fungi. Spencer and Bensen (1982) found that extracts of pine bark suppressed the growth of *Phytophthora cinnamomi* Rands, but noted that the suppressive effects of extracts from hardwood bark compost were stronger and more consistent.

The exact mechanisms by which chemical exudates from organic matter affect specific soilborne fungi are not always clear. In some instances, it appears that the leachates can inhibit the vegetative growth of fungi (Huang and Kuhlman 1991), but in other cases, the chemical extracts may interrupt stages in the life cycle of the fungus. For instance, Hoitink *et al.* (1977) found that leachates from composted hardwood bark could inhibit sporangium formation and lyse germ tubes of zoospores of *P. cinnamomi*, thus preventing host infection. Zoospore production in another water mold, *Pythium aphanidermatum* (Edson) Fitz. has been shown to be inhibited by extracts from pine bark (Huang and Kuhlman 1990).

Water soluble extracts that are leached from various types of mulches can be highly beneficial to seedlings when they suppress fungal pathogens. However, caution is advised in the selection

and handling of organic mulches because some organic materials may be phytotoxic. Organic materials that receive insufficient oxygen during storage or composting can undergo anaerobic breakdown and the resulting fermentation products may be toxic to seedlings (Bollen and Lu 1970, Hoitink and Fahey 1986). Reindeer-moss has been reported to be phytotoxic to jack pine (*P. banksiana*) and white spruce [*Picea glauca* (Moench) Voss] (Fisher 1979), and grain straw residues proved to have deleterious effects on black spruce seedlings [*P. mariana* (Mill.) B.S.P.] (Jobidon *et al.* 1989) in instances where these materials were used as mulches. In both cases, phytotoxicity was apparently indirect via disruption of mineral nutrient uptake (P in the former case, and Mn in the later case). Fisher (1979) postulated that the reduction in P uptake may have resulted from an alteration of mycorrhizal symbiosis.

Biological relationships

Other processes through which mulches may be beneficial in the prevention of seedling diseases involve numerous mechanisms which may be collectively referred to as biological control. Populations and activity of soilborne pathogens are often suppressed by the action of competitive, antagonistic, or hyperparasitic microorganisms which may be stimulated by either the food base or environmental niche provided by certain organic materials and/or mulches. A detailed treatise of specific mechanisms involved in these often complex processes is well beyond the scope of this paper. Accordingly, interested readers are referred to any number of excellent overviews (Adams 1990, Baker 1987, Baker 1968, Baker and Snyder 1970, Baker and Cook 1974, Boland 1990, Campbell 1989, Cook and Baker 1983, James *et al.* 1992).

USE OF MULCHES TO CONTROL *RHIZOCTONIA* BLIGHT OF LONGLEAF PINE: A FLORIDA CASE HISTORY

In the southeastern U.S. longleaf pine (*Pinus palustris*) seedling crops are frequently damaged by *Rhizoctonia* spp. which appear to opportunistically infect seedlings impacted by "sand splash" (Davis 1941, English and Barnard 1989, English *et al.* 1986). Davis (1941) reported reduced damage when seedling crops were mulched with sawdust. Faced with unacceptable losses in the late 1970's and early 1980's at the Florida Division of Forestry's Andrews Nursery, Gilly *et al.* (1985) initiated a field trial to evaluate the influence of cultural practices (i.e., seedling density and mulching materials) and fungicidal sprays on the growth and development of longleaf pine seedlings and the incidence and severity of *Rhizoctonia* blight in longleaf pine seedbeds. Results of the fungicide trials were inconsistent, whereas mulching with hardwood (bark and wood) chips provided consistent reductions in the occurrence of disease with no detrimental effects on seedling production. In the following paragraphs, we review aspects of the mulching trial and present a summary and discussion of pertinent results.

Table 4. Mulches tested for effects on the development of Rhizoctonia Blight of longleaf pinea

Material	Rate
Pine straw (1X)	Operationally applied (6-12 mm layer)
Pine straw (2X)	2X operational rate (12-25 mm layer)
Hardwood bark/ wood chips	12-25 mm layer
Hydromulch®	1180 kg/h[a]

[a] All applied immediately after seeding.

Materials & Methods

Seedbeds were prepared according to customary procedures which included soil fumigation with methyl bromide (98% active ingredient @ 393 kg/ha) and a pre-plant incorporation of 15-0-15 fertilizer at 225 kg/ha). Seeds were sown at densities of 350 seeds/m2 (high) and 150 seeds/m2 (low). Four mulch treatments (Table 4) were applied in each of four replicate plots (ca. 60 X 1.25 m each) distributed in a randomized complete block fashion within each of the two seedbed planting densities.

Systematically located 0.37 m2 life history plots (1 per test plot) were utilized to monitor treatment effects on seed germination and seedling survival. The number of seeds (or seedlings) in each plot was recorded

1 immediately following seed sowing,

2 34 days later, and

3 at the end of the growing season.

Table 5. Production parameters as affected by planting density and mulch treatment [a]

Mulch Treatment	Germination %	Seedlings/m^3	Total Oven Dry Weight (g)	Root Collar Diameter (mm)
Low Density Planting (150 seed/m^2)				
Hydromulch™	26.2a	30.5a	8.6a	9.2a
Hardwood chips	54.7c	86.5b	7.6a	8.6a
1X pine straw	40.2b	76.5b	8.3a	8.8a
2X pine straw	58.3c	82.4b	8.4a	8.8a
High Density Planting (350 seed/m^2)				
Hydromulch™	31.1a	90.1	5.6a	7.4a
Hardwood chips	53.3c	164.c	4.9a	7.3a
1X pine straw	42.2b	125.b	5.4a	7.3a
2X pine straw	54.4c	158.c	5.4a	7.1a

[a] Values within columns and seedbed planting densities followed by same letter are not significantly different at $P \leq 0.05$. Oven dry weight and RCD's differed significantly ($P \leq 0.05$) between low and high density plantings.

All test plots were carefully examined for evidence of *Rhizoctonia* blight on each of six dates between July 5 and November 11. Wooden markers were placed in the ground beside each diseased seedling, and at the end of the test periods, the total number of markers in each infection center (i.e., 1 or more seedlings showing symptoms of infection) were recorded. Incidence and severity of *Rhizoctonia* blight were evaluated by

1 the number of *Rhizoctonia* infection centers/10 m of bed length,

2 the average number of infected seedlings/infection center,

3 the total number of infected seedlings/10 m bed length, and

4 average percentage seedling loss.

At the end of the nursery growing season, two 0.37 m2 subplots were systematically established in each density-mulch plot. The number of seedlings in each of these subplots were counted and ten seedlings were randomly selected from each subplot for determinations of a) root collar diameters (RCD) and b) oven-dry weights.

Results and Discussion

Differences in germination between mulch treatments were significant (Table 5). Highest germination occurred in beds mulched with hardwood chips and 2X pine straw, followed by 1X pine straw and Hydromulch®. This order was consistent in both planting densities. Germination in Hydromulch® plots was so low that end-of-season seedbed stocking (i.e., seedlings per unit area) in "high planting density" Hydromulch® plots was comparable to that in the "low planting density" plots of the other three mulches. Not surprisingly, seedlings grown in sparsely stocked Hydromulch® plots were somewhat larger than seedlings grown in plots with other mulches. Within each planting density, seedlings from beds mulched with hardwood chips were slightly smaller than seedlings from 1X or 2X pine straw plots, even though seedbed densities were comparable. These differences, however, were not statistically significant. Within all mulch treatments, seedlings attained greater oven-dry weights and RCD's when grown at the lower planting density.

Table 6 summarizes results with respect to disease incidence and severity within treatment plots, based on observations performed at the end of the growing season. In both seedbed planting densities the highest losses to disease were sustained in plots mulched with pine straw at the 1X rate. In contrast, losses in plots mulched with hardwood chips were lowest among all four

Table 6. Effects of planting density and mulches on Rhizoctonia Blight of longleaf pine.

Mulch Treatment	No. Inf. Centers/ 10m Bed [a]	Mean No. Seedlings/ Inf. Center [a]	No. Dead Seedlings/10m Bed	Seedling Loss (%)
Low Density Planting (150 seed/m^2)				
Hydromulch™	6.6a	1.5a	9.9	2.7
Hardwood chips	3.3a	1.6a	5.3	0.5
1X pine straw	6.8a	5.3a	36.0	3.9
2X pine straw	4.5a	6.7a	30.2	3.0
High Density Planting (350 seed/m^2)				
Hydromulch™	7.1ac	5.5a	39.1	3.5
Hardwood chips	5.5a	6.4a	35.2	1.7
1X pine straw	11.6bc	14.8a	171.7	11.3
2X pine straw	5.1a	10.6a	54.1	2.8

[a] Values within columns and seedbed planting densities followed by same letter do not significantly differ at $P \leq 0.05$.

treatments. Losses indicated for Hydromulch®-treated plots are deceptively low and misleading due to the very poor germination/stand survival which occurred in this treatment (Table 5). Considering both production parameters (Table 5) and disease occurrence data (Table 6), it is clear that the hardwood chip mulch provided the best treatment overall.

Davis (1941) reported reduced incidence of *Rhizoctonia* infections when longleaf pine seedbeds were mulched with 6-12 mm of sawdust and suggested that mulching might provide useful disease control. Our results support this contention, and of the materials we tested, hardwood chips are clearly the material of choice. While we cannot, on the basis of our studies, eliminate the possibility of some type of biological control being active here, it appears likely that simple physical or mechanical control of sand splash is clearly involved. In this regard, our findings parallel those of Kliejunas *et al.* (1985).

CONCLUSIONS

Results of the case study (above), together with the results and observations reported by others, should encourage forest nursery managers to learn all they can regarding the biology of pathogens causing problems in their respective nurseries. In some instances, the control of diseases caused by pathogenic organisms may be effected via alteration of cultural practices such as seedbed mulching. In Florida, nursery managers have learned that even "re-mulching " longleaf pine seedbeds (i.e. applying a second application of mulch to seedbeds, months after seed germination) is beneficial with respect to reducing losses to *Rhizoctonia* spp. (unpublished data and observations).

One must keep in mind, however, that nature and events are not always predictable, and that even the best of techniques can have an "Achilles heal". In one Florida situation, *Rhizoctonia* caused a foliage blight of loblolly pine (*P. taeda* L.) because the material used for mulch on seedbeds floated up to and lodged in the needles of seedlings during heavy rains, thus facilitating the transfer of inoculum from the soil surface to susceptible needles. Although damage was minor and primarily restricted to low-lying areas of seedbeds, the situation was nonetheless disconcerting for the nursery manager.

A basic understanding of pathogen biology and disease epidemiology (development) coupled with a keen sense of observation and a willingness to experiment are advocated as useful tools in the nursery manag-

ers constant battle to develop and maintain healthy seedling crops.

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Nursery Grown Plants for Wetland Mitigation Projects[1]

Glenn A. Beagle [2]

Abstract – Constructed wetland ponds are being utilized at Lone Peak State Nursery operated by the Utah Division of State Lands and Forestry to produce wetland plants for restoration projects. Restoration and creation of wetlands require a source of wetland obligate plant materials. Use of wetland filters in agricultural, urban and industrial applications provided a partnership to construct several sealed ponds. These ponds are treating water runoff from Lone Peak Nursery operations, filtering disolved pollutants and providing a source of seed and methods for commercial production of Carex, Juncus, Scripus and Eleocharis plugs. As demand increases new infrastructure and methods of producing plants from seed germinants are being developed at Lone Peak Nursery.

INTRODUCTION

The demand for nursery-produced, non-woody riparian plants is increasing rapidly. The national policy of no net loss of wetlands has resulted in many wetland mitigation projects. Water quality improvement projects are also creating demands for wetland plants. Lone Peak State Nursery recognized these trends in 1991 and began looking at various economical methods of producing plugs of *Carex*, *Juncus*, *Scirpus*, and *Eleocharis* species.

Another problem facing many nurseries today is controlling point source pollution from greenhouse operations. In the near future all nurseries will have to address their runoff pollution problems because of stricter enforcement of current laws and passage of tougher new laws.

Lone Peak State Nursery developed one solution to these two problems: a constructed wetland. Formerly, the nursery's greenhouse runoff was drained into a bareroot production field. This field experienced a high incidence of disease and seedling mortality due to saturated soils and high nitrate levels. Greenhouse runoff would then leach into an irrigation canal outside the nursery. All greenhouse runoff is now piped into the constructed wetland ponds where various wetland plants are grown.

In 1992 we looked at the Nevada Forestry Division Washoe State Nursery's method of growing meadow plugs of field collected mix species in 10 cubic-inch-Ray Leach Super Cells. We modified Nevada's system by making initial field collections, sorting the collections into single species, transplanting each species into constructed wetland ponds, and then transplanting from the ponds into 10 cubic inch Ray Leach Super Cells for final growth and sale.

OBJECTIVES OF COMBINED PROJECT

A method of on-site production for wetland plants was desired because field collection of these plants is difficult.

To address the expanding need for wetland plants and improve water quality, Lone Peak set these objectives:

1. Develop commercial methods to propagate five obligate wetland species.
2. Produce and harvest seed from four selected wetland plants.
3. Generate sufficient revenue from wetland plant sales for a self-supporting program.
4. Treat greenhouse waste water before it leaves the Lone Peak property.
5. Grow and market single species by 1994 to support government and private riparian and wetland restoration efforts.

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[1] Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993

[2] Lone Peak Conservation Center Coordinator for Utah State Lands and Forestry ,14650 So. Prison Rd., Draper, Utah 84020 (801) 571-0900

SEARCH FOR POLITICAL AND FINANCIAL SUPPORT

Building support was necessary to fund the construction phase of the project. The Utah Department of Agriculture (UDA) was a strong advocate for the project. Because it could see benefit from a supply of wetland plants for agricultural filter strips, the UDA provided funding and collaboration with the USDA Soil Conservation Service (SCS) to design a collection and water storage system to Lone Peak's operational specifications.

Utah Power, a private utility company, had begun using native plant communities to effect water quality and soil stability. Utah Power saw the long-term benefit of creating a commercial source of wetland plants and became a principle donor to the project by providing a construction grant.

The USDA Forest Service, through state and private forestry programs also helped Lone Peak with funding to produce plants for the reclamation of riparian systems. Lone Peak's methods for production will provide wetland plants for out planting. This ability to commercially produce wetland plants assisted in building support for the project.

DESIGN AND CONSTRUCTION OF RUNOFF COLLECTION SYSTEM AND PONDS

The constructed wetlands consist of four ponds lined with a 30 mil plastic membrane with inlets for runoff and irrigation water. We wanted a sealed system to prevent any waste water from leaching out of the ponds and to allow monitoring of pollutant levels in water drained from the ponds. Each pond contains a French drain which allows adjustment of the water table depth and draining of all pond water for plant harvesting operations. A mixture of sandy loam topsoil

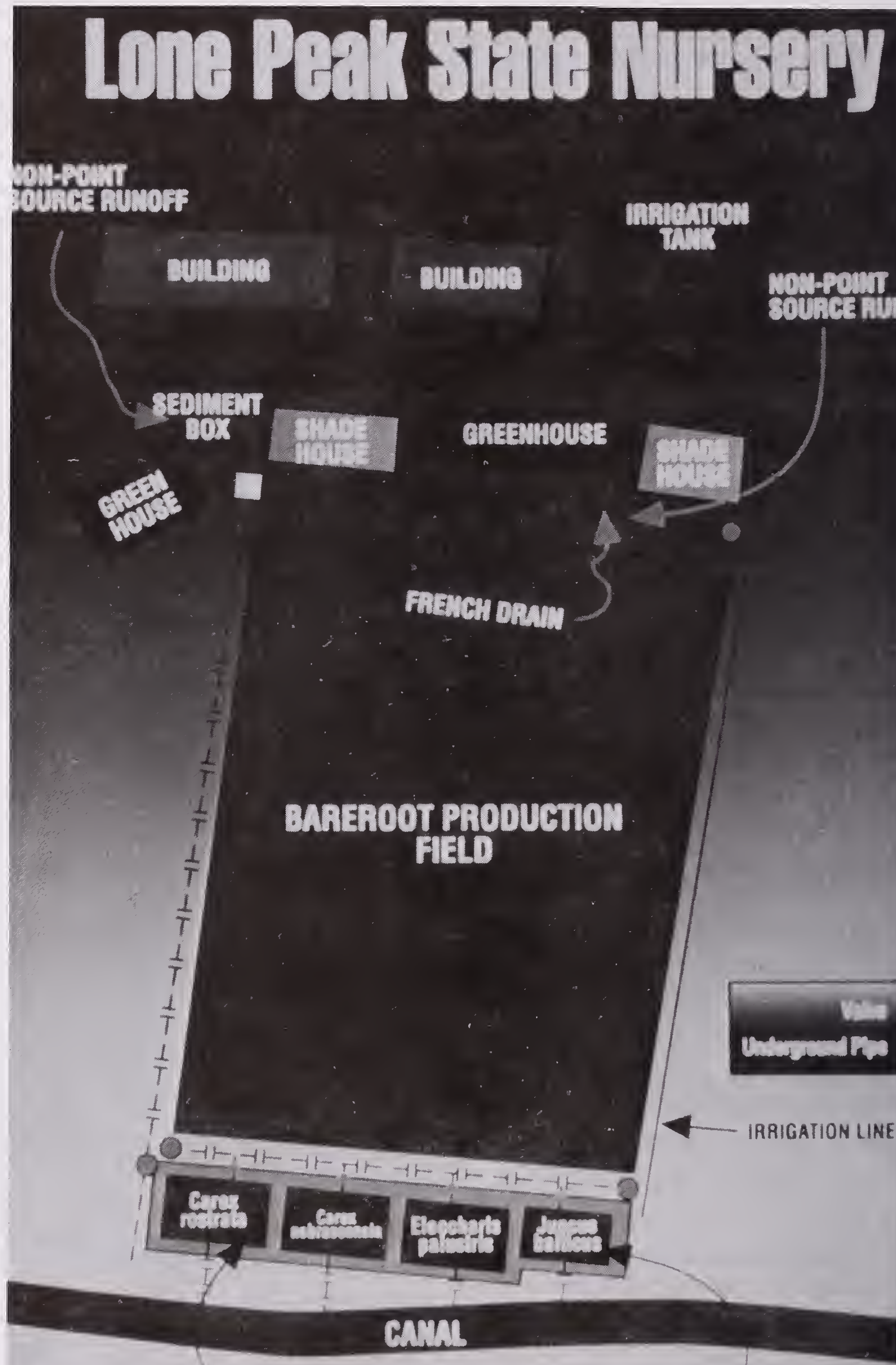

Figure 1 – Greenhouse and irrigated shadehouse above a 2-acre bareroot production field. The constructed ponds are at a lower grade at the bottom of the field. Water runoff is introduced through drainiage pipes and ditches.

and washed concrete sand was placed in the ponds to a depth of 2 1/2 feet. This soil mix was selected to prevent introduction of weed seeds from nursery soils and to provide a coarse textured, easily drained soil.

Water enters the pond via two methods. Non-point source and greenhouse runoff are captured in a French drain and settling box below the greenhouse and piped underground to the ponds (Fig. 1) The field irrigation system is connected to the underground drains and pond inlet piping. This connection has proven valuable. Runoff sediment accumulates quickly in the underground pipes and the entire system can be flushed under pressure with irrigation water. Also, during dry summer months it has been necessary to supplement runoff with irrigation water to maintain proper water levels in the ponds.

The wetland design has been in use for one and a half years with very few problems. The only change in design we recommend is reducing the width (6 feet) and height (3 feet) of the pond dikes. They are over-designed for project needs and significant construction dollars could be saved with smaller dikes.

WATER QUALITY LIMITATIONS OF CONSTRUCTED WETLAND

Testing for different dissolved pollutants and analyzing the efficiency of ponding and filtering water through obligate plants proved expensive and not within the budget design. A further complication to water quality testing was the introduction of non-point source water to the system. The greenhouse and shadehouse runoff became a minor component as compared to the non-point source water that has been collected. Lone Peak's system required greater amounts of water than the greenhouse operation could provide. The collection of greenhouse run off by French drains proved ineffective. All greenhouse run off may not be captured by the French drains. We recommended that to make pipe connections from greenhouse floors drain to the ponds.

VEGETATIVE PROPAGATION SYSTEM FOR COMMERCIAL PRODUCTION

The propagation system developed for the ponds is designed to vegetatively produce single species riparian plant plugs. The design minimizes field collection costs, transplanting losses, and labor costs. The coarse textured pond soil easily falls away from plant roots during harvesting which limits soil loss. The soil is saturated to soften it for planting and harvesting.

Initial plants for the ponds are from wild collections. Collected plant material should be treated like bareroot tree seedlings. Wild collections do not store well and must be planted quickly. Cold storage of material for longer than 2-3 days appears to reduce transplant success. The wild collections are first potted and grown to maturity. When the plants are correctly identified, single species are planted in each pond. *Carex nebraskaensis*, *Carex rostrata*, *Juncus balticus*, and *Eleocharis palustris* are currently growing in the ponds.

The ponds are planted with plugs containing 2 - 3 shoots on a one-foot by one-foot spacing. After nine months when the ponds contain 20 - 25 shoots per square foot, 40 percent of the surface area is harvested. Individual shoots and rhizomes are divided out, and individual plants are potted into 10-cubic-inch Ray Leach super cells or 29-cubic-inch D-pots. Pond soil is replaced after each harvest to fill in holes and level the soil surface.

Potted plants are cultured outdoors for one-two months. When multiple shoots appear, these are divided into single shoots and re-potted. Several divisions occur each growing season with each division increasing the number of plugs by approximately 50 percent. (Fig. 2)

We are still experimenting with and learning about the best production methods for riparian plants. We are investigating the following methods:

- Trials have been conducted to determine the optimum growth container for *Carex* species. Four-inch-deep geranium pots, 29-cubic-inch D-pots, and 10-cubic-inch Ray Leach tubes have been tested. The geranium pots appear to allow the greatest rhizome development because they have the largest surface area. The D-pots and geranium pots are used for initial potting. Ray Leach tubes are used at the final division.

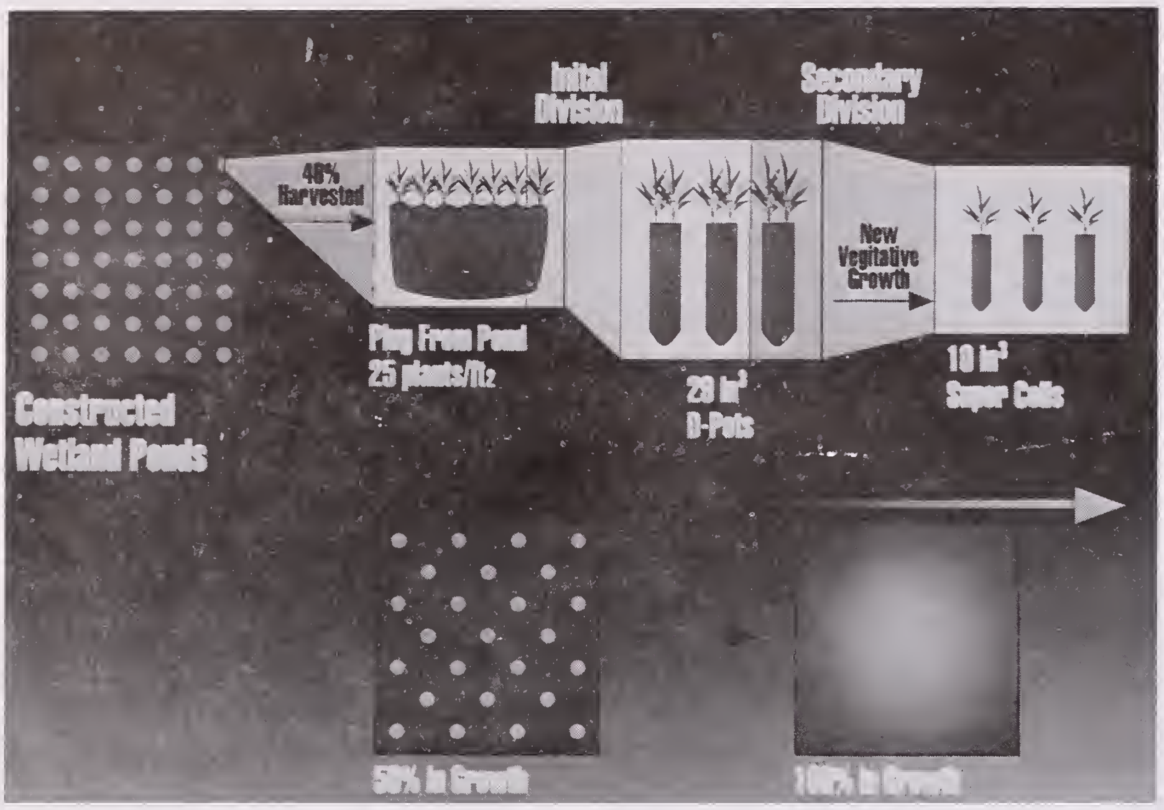

Figure 2 – Harvesting 40 percent of pond surface area for vegetative starts. Several growth periods and splitting of new material produced in tubes to increase the yield. Pond area recovers and is available for future harvests and seed collection.

- Managing the water levels in the ponds is very important for culturing different species. Our experience and information supplied by the Aberdeen PMC indicates that the optimal water level for *Carex rostrata* is at the soil surface, for *Carex nebraskaensis*, it is 1-2 inches above the soil surface, and for *Juncus balticus*, if 1-2 inches below the soil surface. Growth reductions occurred in these species under different water levels.
- Harvesting plants from dense, wet stands in heavy soils is difficult. We are currently evaluating several tools to ease this process.
- Labor costs can account for a large portion of the cost of wetland plant production. Field collection, transplanting, and plug division all require many worker hours. Any methods which may save labor dollars should be considered. The construction of a wetland on nursery grounds allows on-site collection of plants, thus reducing overall production costs.
- The potential exists to produce wetland plants from seed. Seed propagation has several advantages lower field collection costs, less required growing area, and no requirement for a constructed wetland. Obstacles to seed propagation include lack of knowledge on pre-germination treatments, and seed storage viability, and limited availability of local seed sources. Lone Peak's seed research as been concentrated on the propagation of *Scirpus acutis* and *Scirpus maritimus*. Initial plans called for planting *Scirpus acutis* in one constructed wetland pond. After working with this species it was apparent that vegetative propagation was not practical due to its large size. We are currently exchanging information on pre-germination seed treatments for wetland species with the SCS Aberdeen Plant Materials Center (PMC). Many treatments and stratifications have been tested with variable results.

NEED FOR MORE GROWING AREA

The demand for wetland plants for reclamation projects has exceeded our current vegetative production capabilities. Wetlands have been incorporated into agricultural, urban and industrial planning. Mitigation and conservation uses of wetlands for water development projects have created a demand for reasonably priced wetland plants.

Lone Peak State Nursery's existing greenhouse is partly utilized to grow wetland plugs after "division" and grow *Scirpus* spp. from seed. Additional greenhouse space is needed for future wetland plant production as we convert to the use of seed

germinants. A closed greenhouse irrigation system will allow the monitoring of nutrient uptake of individual plant species. Conversion of Lone Peak's existing wetland ponds to seed production has the advantage of providing a known seed source of single species. The ponds can continue to be a component for water treatment of our existing greenhouse and non-point pollution sources.

TRANSFER OF TECHNOLOGY

The production of wetland plants is a newly emerging aspect of the nursery field. Lone Peak State Nursery has been fortunate to receive assistance for this project from many agencies including the USDA Soil Conservation Service, USDA Forest Service, Nevada Division of Forestry, Utah Power Corporation, and the Utah Department of Agriculture. The constructed wetland project was developed to produce salable plants and develop practical propagation techniques. The resulting information and technology may be used by other public and private growers to address wetland production needs. Lone Peak State Nursery could supply plantlets or seed from our constructed wetland for private nursery propagation.

Many unknowns still exist in propagating wetland plants vegitatively and from seed. Development of seed collection, processing, and germination techniques may yield more economical production methods. Our wetland plant production will continue to be a cooperative project among federal, state, and private organizations.

For more information contact:

Glenn Beagle, Coordinator
Lone Peak State Forest Nursery
801-571-0900

Figure 3 – Pond in foreground containd *Carex rostrata* after six months of ingrowth

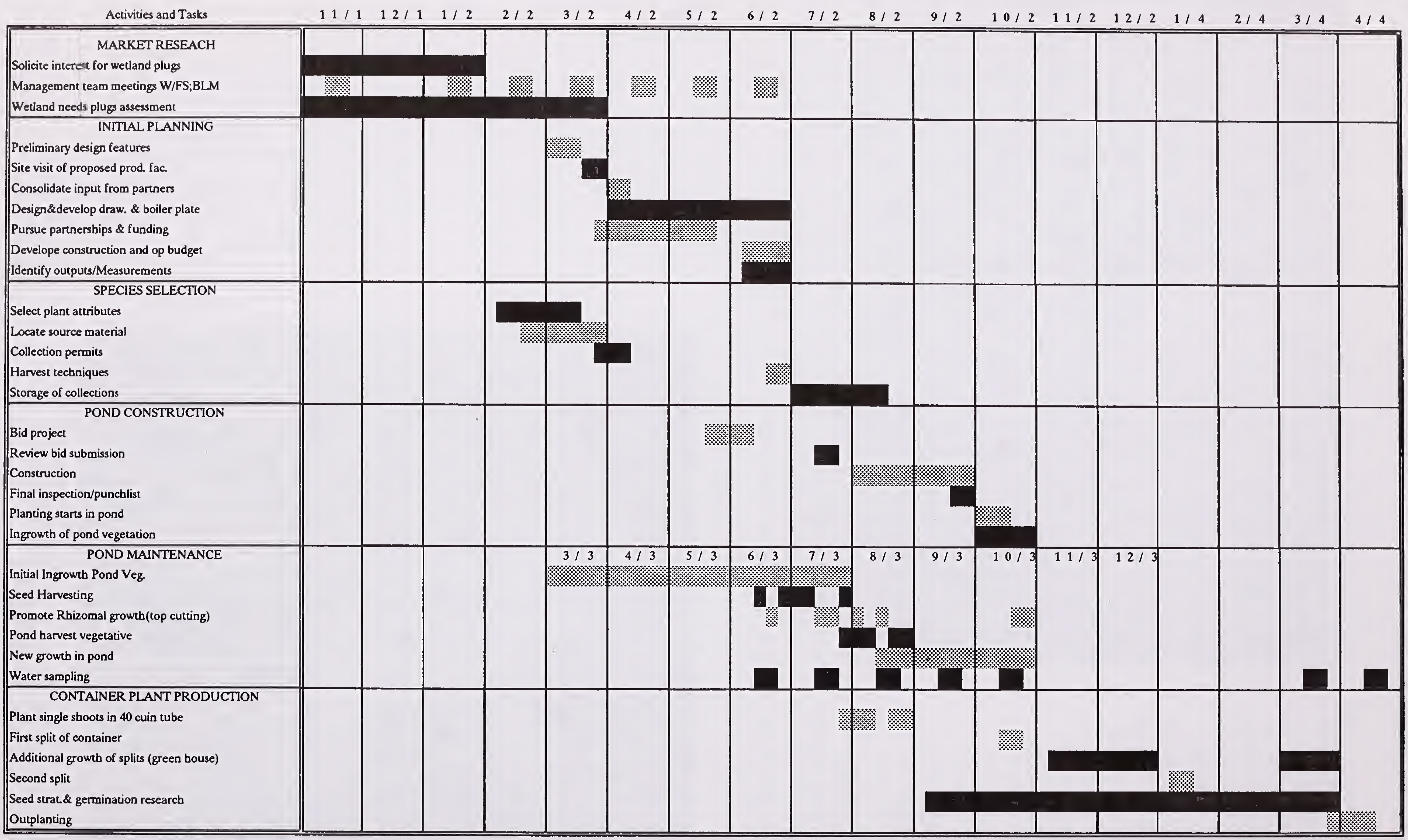

Figure 4 – Chart displaying project activities with a time line from the eleventh month of year one through the fourth month of year four

Plug + One Production of Colorado Blue Spruce at the Colorado State Forest Service Nursery[1]

Abstract – Plug+1 refers to a combination of two growing environments. A small greenhouse grown plug is produced then transplanted into outdoor beds. Article outlines greenhouse and field production methods followed at the Colorado State Forest Service Nursery for Colorado blue spruce *(Picea pungens* Engelm.).

Randy D. Moench[2]

Plug + One (P+1) refers to a unique production method for many Great Plains conservation nurseries. The method was originally developed in Oregon in 1971. It is now a common method for reforestation nurseries in the northwest (Hahn, 1984).

It is a combination of two growing environments – the greenhouse and the bareroot field. The term plug refers to the greenhouse-grown container seedling. Container sizes can range from miniplugs–only one cubic inch in size–to ten cubic inch cells. Containers are then transplanted to the fields in spring, late-summer or fall for an additional growing season in outdoor transplant beds.

In only two growing seasons a large caliper, bushy topped and heavily rooted seedling is produced, equivalent in size to that of the more traditional 2+2 or 2+1 transplant. The mop-like appearance of the root system is the most unique feature in comparison.

PRODUCTION METHOD

Container Phase

Originally, the Colorado State Forest Service Nursery (CSFS) began P+1 production using a large ten cubic inch container – the "Ray Leach Super Cell." Demand for the seedlings and limited greenhouse production space led to using the smaller four cubic inch "Ray Leach Pine Cell." This change doubled greenhouse production capacity.

Seed is sown in late August and the crop actively grown until January. Growing conditions are described in Table 1.

With most of the growing and hardening occurring during fall and winter, stagnant air develops due to minimal air circulation. Grey mold *(Botrytis cinerea)* is a serious problem that is controlled by preventive applications of fungicide on a bi-weekly basis.

Table 1.—Greenhouse Growing Conditions at CSFS Nursery.

Day Temp	70-75°F
Night Temp	70-75°F
Supplemental	All-night
Lighting	Intermittent
CO_2	700-800 ppm
Fertilizer	N = 100 ppm
	P = 50 ppm
	K = 74 ppm
	+ micros
Mycorrhizae	*Rhizopogon* spp.

Stock hardening is begun in January. Supplemental lighting is turned off, nitrogen levels reduced to 60 ppm and temperatures are gradually reduced to near outdoor ambient conditions. By late March the stock is ready for transplanting.

Transplanting

Due to work load impacts from the seedling distribution season and other production priorities, the stock is held in the shade house until mid-August when it is transplanted to the field (Figure 1).

A spring flush is experienced in the shade house but continued growth is not actively encouraged. Stock is watered and fertilized on an as needed basis using the 60 ppm nitrogen solution.

Transplant beds are prepared and phosphate fertilizer, 0-46-0, applied prior to planting. Goal 1.6E herbicide is applied for weed control. A twin row tree planter is used for transplanting. Two passes are required to make up the four row beds. Transplant density is approximately four seedlings per linear foot.

After planting transplant fields are watered heavily to minimize transplant shock and provide cooling. As summer temperatures moderate irrigation is reduced to maintain bud dormancy and prepare for winter.

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

[2] *Nursery Manager for the Colorado State Forest Service Nursery, Colorado State University, Fort Collins, Colorado.*

By early December, time of soil freeze up, four to six inches of new root growth has occurred. The seedlings are well established in the beds and no frost-heave problems are experienced overwinter.

Field Growing

Beginning in late April ammonium sulfate (21-0-0) is applied biweekly at a rate of 200 pounds product per acre totalling about 700 pounds in a season. Fertilization ceases around mid-July.

Colorado's arid climate means no disease problems are experienced during the second growing season. *Fusarium* root rot, a common disease with many Great Plains nurseries, is not a problem here yet. The CSFS Nursery has never used soil fumigants for disease or weed control.

Rare occurrences of Douglas-fir tussock moth have been noted in nursery windbreaks but insect populations have never reached problem levels. Climatic conditions mean no top mowing is necessary and no root pruning or wrenching is done. Stock is ready for harvesting in mid-November.

Figure 1 – Lifting P+1 Transplants of Colorado blue spruce

DISCUSSION

Container size greatly impacts finished seedling size at the CSFS Nursery. The ten cubic inch containers produced a seedling 14" to 18" tall with 1/2" caliper. Changing to the four cubic inch container reduced height to six or eight inches with 1/4" caliper. Outplanting results and popularity with customers have remained the same despite the change.

Other Great Plains conservation nurseries are experimenting with much smaller two cubic inch containers. Results so far indicate two growing seasons outdoors may be required to attain a size similar to 2+1 or 2+2 transplants commonly available in the region.

The P+1 methods seems to provide the best of both worlds – the superior fibrous root systems from container growing and the hardy foliage from the outdoors.

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Using Geographic Information Systems in a Nursery[1]

Stephen C. Westin[2]

Geographic Information Systems (GIS) are computer based systems which combine maps (spatial data) with information that describes features found on those maps (tabular or attribute data). After the maps are converted to a computer format (usually by digitizing) and the attribute data is entered into a database management system the GIS software can be used to perform analyses and generate map products utilizing both types of data.

Examples of possible applications of GIS technology to the nursery setting include:

1. Tracking and mapping of species distributions across several years. Querying the system for the location(s) of a specific species, seedsource, or age group. For example a query such as "find the 2-0 shortleaf pine from source 'Jumbo'" could be conducted and the results mapped.
2. Mapping the results of soil surveys and nutrient testing and then using that information to graphically examine the impact of soil characteristics on seedling growth and yield (derived from history plot and seedling inventory data).
3. Tracking and mapping the results of insect and disease monitoring efforts. Patterns across years are more readily apparent using a GIS.
4. Tracking and mapping cultural activities such as fertilization, herbicide and pesticide application (where, when, rate), mulch application, etc.
5. Using the spatial component of the GIS to help match bed space to available seed stocks.

The potential uses of GIS in a nursery setting are limited only by the needs and imagination of the people using the system, and the data available for incorporation into the system.

The Missouri Department of Conservation is currently developing a GIS for the George O. White State Forest Nursery in Licking, MO.

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[1] Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993

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Irrigating and Fertilizing To Grow Better Nursery Seedlings[1]

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Abstract – At the time of loblolly pine seed sowing, we recommend soil nutrient concentrations (in parts per million) of: 350-400 for Ca, 80-90 for K, 80 (BrayII) for P, 50 for Mg, 0.3-3 for Cu, 3-8 for Zn, and 0.5-1.2 for B. Soil pH should be 5.1-5.9. An initial N application of 10-15 kg/ha (11-17 lbs/acre)should be made when the elongating stems above the cotyledons are 2.5 to 3.5 cm(1 to 1-1/2 inches) long. A second equal N application is needed 10 to 14 days later. Three applications of 15-30 kg/ha N should be made at intervals of 10 to 14 days. Seedlings from late sowings require more N than those sowed earlier. If rains are frequent, N applications should be skipped or reduced. By mid-July, seedlings heights should be 15-20 cm (6-8 inches), and N applications should be suspended. In late September, seedlings should be undercut and 22 kg/ha (20 lbs/acre) of N should be applied.

Between germination and the first N application, water should be applied daily to avoid any moisture stress. After seedlings are established, beds should be watered when tension meters at 20 cm (8 inches) read 30 centibars. After mid-July, water when readings reach 50 centibars, or when there is danger of scorch on exceedingly hot days.

In this paper we describe a system for producing excellent loblolly pine seedlings for planting in southern forests. The system, which has taken years to develop, appears to be working well. Proof of that will depend upon results of outplanting tests, but there are strong indications that the seedlings we are producing will be better than those coming from most southern forest nurseries. One reason they will be better is because they are being graded to get rid of inferior individuals. Another reason is that top/root (T/R) ratios are near ideal. In our approach, irrigation and fertilizer applications are less generous. The seedlings that are produced have smaller tops, and do not require pruning. And because less fertilizer and water are applied, there is less possibility of polluting groundwater under the nursery.

We present the findings with no details on metabolic pathways or complex root morphology. In the main, however, we describe a system for growing loblolly pine nursery seedlings and in less detail present current practices that appear to be equally effective for producing a good and consistent crop of hardwood seedlings.

BACKGROUND

This new approach to growing loblolly pine seedlings began with research on sweetgum and other species of hardwoods. Nursery-grown hardwood seedlings were performing erratically in the field. Some were growing quite well and others were growing very, very poorly. Some of those early research findings with sweetgum are summarized at the outset.

A decade ago, we were observing uneven results of sweetgum plantings. A fair proportion of the seedlings that were being planted were growing quite well, but the proportion was not high enough to make a satisfactory stand. And many of the planted trees were growing slowly, if at all. Our conclusion was that good performers had to differ from the poor performers in some major way.

that would be recognizable in nursery seedlings. Our goal, therefore, was to separate potentially good and poor performers through grading in the nursery.

There was little new about the idea of grading nursery seedlings. People have been trying to do that for as long as there have been forest tree nurseries. There was, however, no detectable enthusiasm among nurserymen, who had become comfortable with the practice of selling all of their seedlings rather than culling and discarding some of them. We heard some comments about culling being impractical or inappropriate in a 1980's nursery operation. We ignored the comments and plunged ahead.

Our research showed that the number of strong, first-order lateral roots (FOLR) a nursery seedling possessed was a strong

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

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indicator of its probable performance after outplanting. Individuals with the fewest FOLR were least competitive both in the nursery and in forest environments (Kormanik 1986, Kormanik and Muse 1986, and Ruehle and Kormanik 1986).

We suspected that the proportions with high and low performance potential in seed lots from individual mother trees were genetically controlled, but to test that theory we had to be able to produce a consistent crops of seedlings regardless of the nursery in which they were grown. We wanted sweetgum seedling that fell within a specific size range, and we wanted differences in performance potential to be fully expressed after a year in nursery beds.

During the late 1970's and early 1980's we had developed a protocol for growing sweetgum in our experimental nursery when the original work on lateral root development was done (Kormanik 1985, Kormanik and Ruehle 1987). With that protocol, number of strong FOLR was a meaningful measure of probable field performance of sweetgum (Kormanik 1986).

In 1984, we began work with loblolly pine to determine whether any of our findings with sweetgum would be applicable to it and other conifers. At that time, and to this day, there is no generally accepted protocol for nursery production of loblolly pine seedlings. Seedbed densities, soil fertility, fertilizer application schedules, and irrigation schedules vary widely among nurseries and among fields within nurseries. As we began to study loblolly pine seedlings, it became apparent that these variations in nursery conditions were influencing FOLR development of loblolly seedlings. Differences in cultural techniques also were frustrating our attempts to obtain seedlings within a narrow range of sizes for our research.

At that time, our specific research objectives were: (1) to develop frequency distribution curves of seedling FOLR numbers for mixed seedlots and lots from specific mother trees, (2) to correlate height and root collar diameter with number of FOLR, and (3) to determine heritability values for FOLR development. To complete those objectives, we needed to produce seedlings within a specific size range without clipping tops or wrenching roots. We wanted seedlings ranging from 25 to 36 cm (10 to 14 inches) tall.

EARLY OBSERVATIONS

It didn't take long for us to realize that production nurserymen had a conflicting set of objectives. We wanted loblolly pine seedlings to grow at apace that would permit expression of differences in outplanting potential. Nurserymen wanted to grow seedlings of uniform size with little or no culling. To meet their objectives, they were, and still are, providing luxurious quantities of nutrients and water. Under these conditions, inherently superior loblolly seedlings get too large, so nursery workers expend considerable effort clipping tops and wrenching roots to get a final product that is small enough to plant. Their procedures are described in the Nursery Handbook (USDA 1984).

Thirty years before, Wakeley (1954) recognized that such improvements in nursery culture hampered the development of a morphologically based grading system for southern pine seedlings. The purpose in nurseries, however, was not to make a grading system work, it was simply to eliminate the need to grade seedlings.

We found that all nurseries were clipping seedling tops and wrenching roots several times during the year to produce seedlings with uniform stem characteristics. Root morphology was quite variable among these seedlings with uniform top sizes. Furthermore, even in individual nurseries, top clipping and root wrenching schedules were varied to compensate for the differences in soil productivity of individual fields.

When we began to compare fertilization practices of different nurseries, we found little similarity among them. There even appeared to be little similarity among fields within the same nursery. It was not unusual for P, Ca, K, and Mg levels to vary by 50 to 75 percent among individual fields, and the levels were sometimes double that which we had found ideal for sweetgum. Fields considered good for producing seedlings characteristically had significantly different fertility levels and even different ratios of specific nutrients than did less-desirable fields. We also found little relationship between irrigation patterns and the seasonal requirements of the seedlings for moisture. If water was applied daily in May, it also was

applied daily in August, regardless of the plants' need for water. Little consideration was given to soil texture when prescribing irrigation interval and duration and fertilizer applications.

WHAT WE DID

Early observations led to the conclusion that we needed a target seedling density for seedbeds and a baseline value for soil fertility. By "baseline value" we mean the nutrient content of the soil when seeds are sown. In our experimental nursery we adjusted the nursery beds to a uniform density of 258-280 seedlings/m2 (25-28 ft2), used the same fertility baseline we had found so effective with sweetgum, and then applied nitrogen at levels up to 280-308 kg N/ha (250-275 lbs/acre), which was the quantity most commonly applied in southern nurseries in the mid-1980s. We applied these in equal increments on the same date that the commercial nurseries did. We avoided topclipping and root wrenching because we wanted a natural balance between roots and tops to occur.

This system produced excessively large seedlings but root morphological differences were correlated with stem characteristics. Seedling sizes were easily stratified by FOLR numbers. Seedlings were sometimes twice as large, up to 75 cm, (30 inches) as those being shipped to the field for outplanting and were more difficult to outplant. The survival of 70-80 percent under research conditions was acceptable. We did, however, question whether such good results could be sustained under commercial planting conditions.

At about this time, we were able to demonstrate how photosynthates were partitioned between roots and tops of loblolly pine seedlings during the entire year. We were able to do so using assays for several sugar-metabolizing enzyme reactions (Sung et al. 1989, 1993). During our physiological and morphological investigations, seedlings were excavated weekly from several different nurseries.

We found that little root growth occurred in June, July, and early August. These observations had a major impact on our thinking. Fertilizer applied at this time was being transformed into top growth. Since our tops were generally too large, we saw a need to limit fertilizer application from June to early August.

We also found, as others had, that we could raise loblolly to about any size we desired, but that we could not stop rapid mid-season elongation without top clipping or root wrenching. With information on seasonal and periodic carbon allocation and utilization patterns between roots and stems, we decided to alter our research direction. **Instead of continuing to study how to grow loblolly pine seedlings, we tried to determine how the seedlings grew.**

We soon discovered that terminal buds developed on unclipped loblolly pine seedlings in late August or early September. At that time, there was a dramatic shift of carbohydrate allocation and metabolism from stems to roots and the root systems began to expand rapidly. Late-summer clipping resulted in multiple tops

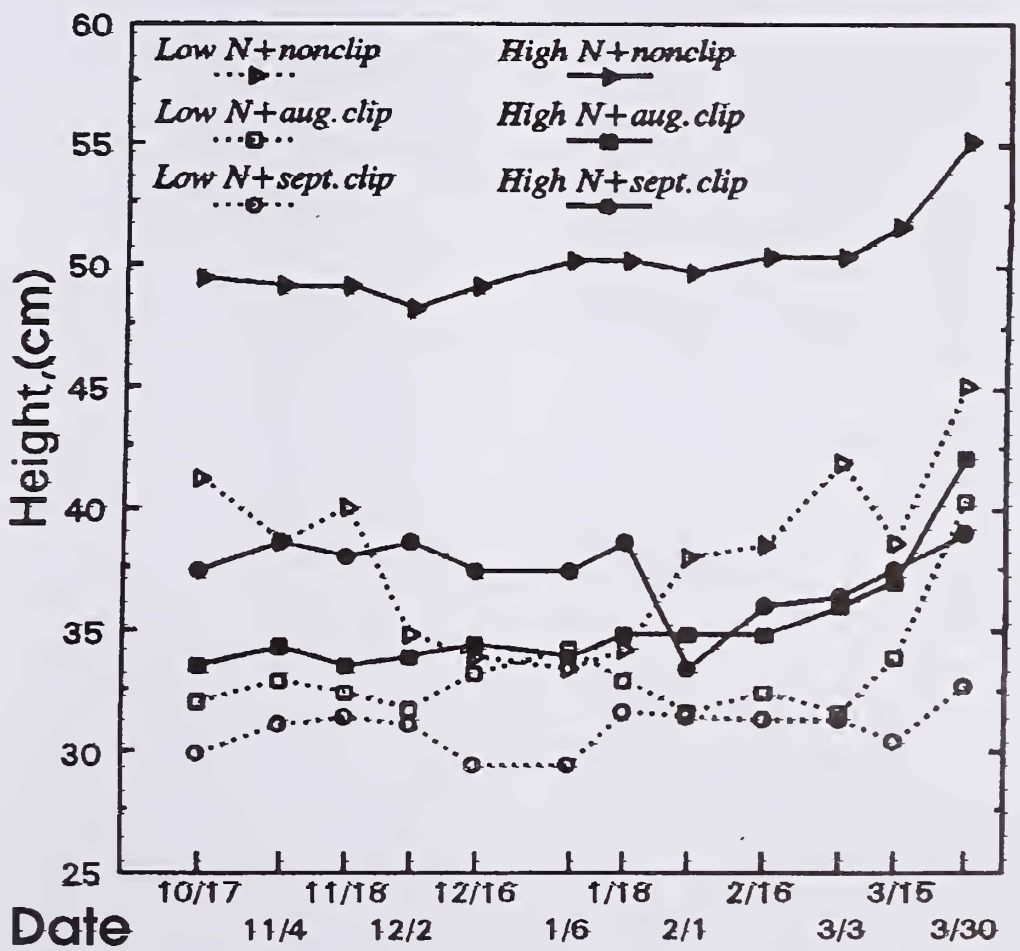


Figure 1.–Effects of high and low levels of nitrogen (308 - 84 kg/h) applied in five equal aliquots on height of clipped (August and September) and nonclipped loblolly pine seedlings.

on the seedlings, and these new tops acted as carbon sinks. They altered the normal late-summer transition from top growth to root development.

We began a series of nitrogen trials with loblolly pine using the fertility baseline developed for sweetgum. Our notion was to apply only enough nutrients to achieve our target size of 25-36 cm (10-14 inches) in seedlings that were not top-pruned or root-wrenched. Examples of our early results are shown in Figure 1. In this particular study we used 308 kg N/ha (275 lbs N/acre) as our high nitrogen level. This level was commonly used N in nurseries at that time. The low level of nitrogen was 75 lbs N/acre. The N was applied in five equal amounts whether at the high or low rate of application. No rootwrenching was done but the seedlings were clipped twice as was the policy inmost nurseries growing loblolly pine.

In Figure 1 it can be seen that whether the seedlings had high nitrogen and were clipped, or low nitrogen and were clipped or not clipped, they were of comparable sizes. It was evident that more nitrogen was being applied than the small root systems in the early season could capture and that the luxurious quantities were resulting in excessive height growth. Top/root ratios in October and November were in excess of 8:1 on these large seedlings, but by early to mid January dropped to 3 or 4:1. The T/R ratios of clipped seedlings were 3 or 4:1 beginning in early November.

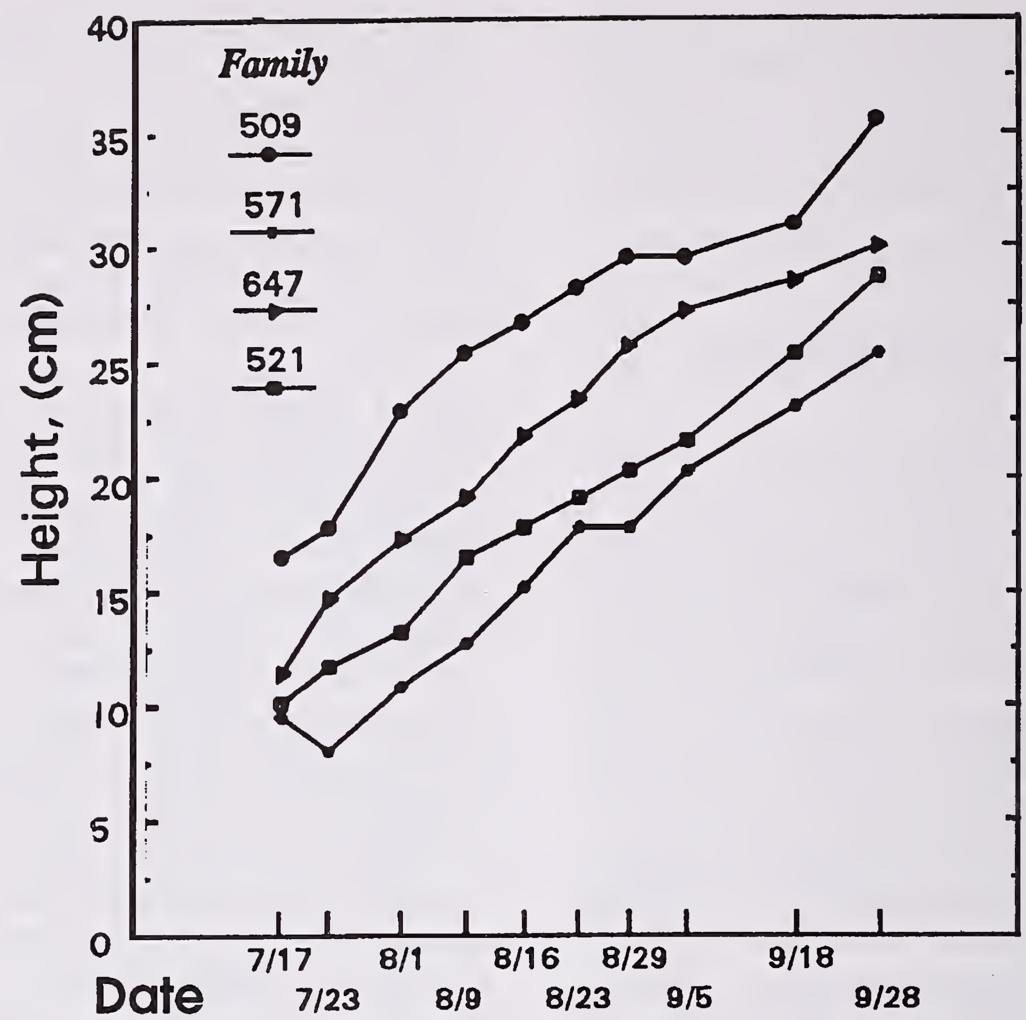


Figure 2.--Heights of half-sib progeny from 27 loblolly pine mother trees in late September after normal bud set and undercutting in mid September. 23 mother-tree progenies were all distributed between families 509 and 521. Approximately 100 kg N/h were applied throughout the growing season.

FERTILIZER AND IRRIGATION PROTOCOLS

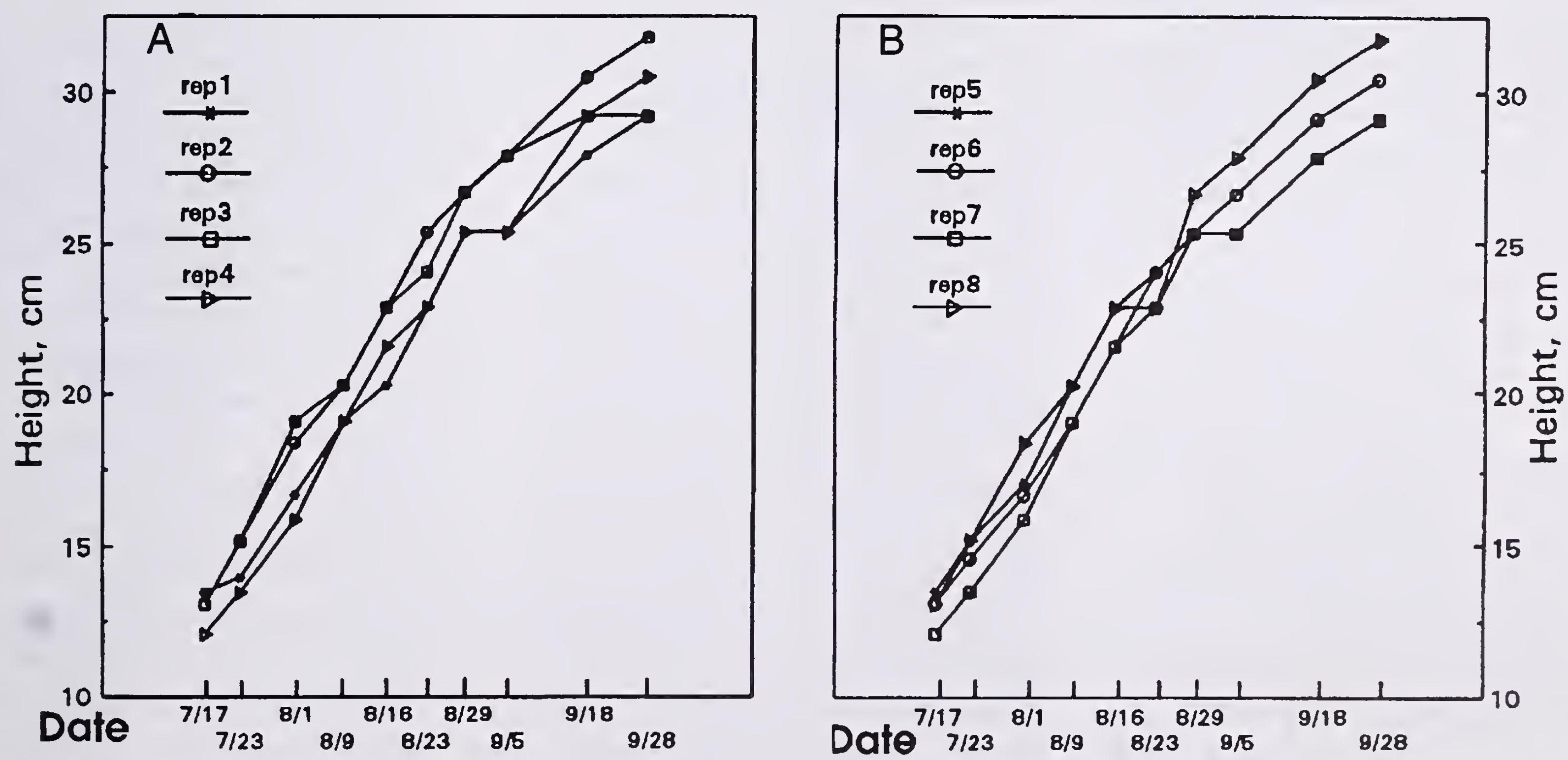
These early nitrogen trials revealed that when loblolly seedlings reach 15-20 cm (6-8 inches), whether in early June or mid July, secondary needles developed. If secondary needles appeared in June, the seedling's growth was excessively stimulated by nitrogen application. Eventually, we found that by applying nitrogen at 11-17 kg/ha (10-15 lbs N) at 10-day intervals, we could get seedlings to 15-20 cm (6-8 inches) by mid-July. We found it was good to apply one of our N applications in mid-July and then let the seedling develop until mid-September without further N application. By mid-September, at least 90 percent of the seedlings developed terminal buds. Those seedlings were undercut to 20 cm (8 inches) and a final N application of 22 kg N/h (20 lbs/acre) was made. Undercutting breaks feeder roots and stops taproot elongation. It also causes a wounding response at the time when the root system has replaced the top as the major carbon sink (Sung et al. 1993). During the next 30-45 days, fine feeder roots, mycorrhizae and RCDs increase rapidly. Tap roots do not expand appreciably, and since we began the procedure about 5 years ago we have experienced essentially no bud break after mid-September.

Nitrogen control is complicated by the fact that weather factors cause sowing dates for stratified seeds to vary by 30 days or more between years and by 14 to 20 days in any given year. It is therefore impossible to prescribe the date when N application should begin and how often it should be applied. We found, however, that an initial N application of 10 to 15 kg/ha (11 to 17lbs/acre) should be made when the elongating stems above the cotyledons are between 2.5 and 3.5 cm (1 to 1-1/2 inches). At this time, the root system is just beginning to expand and some feeder root development can be observed. This first application is usually applied towards the end of May. A second equal application is made 10 to 14 days later. The next three applications are again at 10 to 14 day intervals, but the rates may vary from 15 to 30 kg/ha (17 to 27 lbs/acre), depending on when the seed were sown. Seedlings from late-sown seeds can be pushed to attain the height of seedlings from earlier sowings. If rain and accompanying thunderstorms are frequent, the seedlings may start to elongate rapidly and any of these N applications can be reduced or skipped.

The important point is that by mid-July seedling heights should be 15-20 cm(6-8 inches). Usually we find that by mid-July we only need to apply about 90 kg N/h (80 lbs/acre) to get seedlings to these desired heights. In stormy years, we have used as little as 56 kg N/h (50 lbs/acre) for the entire growing season. In a very dry season, 100 kg/h (89 lbs/acre) were needed to attain the same heights.

Irrigation protocols, which were developed simultaneously with fertilizing protocols, also were based on producing seedlings of the desired size. After the fertility baseline for a nursery is achieved, the major cause for variation in seedling development may be water availability.

Between germination and the first N application, the young succulent plants should not be subjected to any moisture stress. Initially, the beds are watered daily to assure good germination and establishment. Up to the time the seedlings are 15-20 cm tall, the beds should be watered when tension meters at 20 cm (8 inches) depth read 30 centibars. After the final mid-July N application, watering is needed only when the readings reach 50 centibars. However, irrigation of short duration may be required during abnormally hot days in midsummer. Even then, however, irrigation is seldom needed when soil tension is less than 30 centibars. Maintaining moisture at close to field capacity can result in rapid stem elongation that can only be stopped by clipping tops, wrenching roots, or imposing severe moisture stress.



Figures 3A and 3B.--Heights of loblolly pine seedlings from mixed seedlots receiving 90 kg/ha of N during the growing season in beds where the nursery fertility baseline had been established. Data are illustrated in two groups for greater legibility.

BASELINE FERTILITY

After we were satisfied with our irrigation and nitrogen protocols, we were ready to set a standard soil fertility baseline. By 1989 we were able to test half-sib seedlots of 27 mother trees to determine how baselines affected development of individual seedlots. Figure 2 contains four of these half-sib progeny seedlots. Mother tree 509 produced the tallest seedlings, 521 the smallest, and 571 and 647 midway between. By late September when seedlings had completed height growth, the average sizes of progeny from all families were within target sizes before the seedlings were undercut and given their final nitrogen application of 22 kg/h (20 lbs/acre). At this point we felt that we could consistently obtain seedlings within the target range and we could predict the frequency distribution of seedlings based on FOLR development(Kormanik and Ruehle 1987, Kormanik et al. 1990, Kormanik et al. 1991).

However, since most nurseries were using mixed seedlots, we further tested the baseline with mixed seedlots in different nurseries. Figures 3A and 3B contain the heights obtained from eight different replications from the 1990investigations. They are reported in two groups to make the graph more legible. Typically, we find that loblolly seedling crops are more uniform when grown in mixed seedlots than in mother-tree seedlots.

Fortunately, we found that a single baseline appears to be effective in all three Georgia State Nurseries for both conifers and hardwoods, even though the soil textures vary from sandy clay loam in one to almost a sandy loam in another.

In all the fields in these nurseries, the fertility is similar or soon will be. We found that it may take up to 5 years of manipulating nutrients to achieve the desired levels. Nevertheless, the effort is necessary to produce the kinds of seedlings that are needed. Once the fertility baseline is achieved, seedling size can be controlled through the scheduling of nitrogen and water applications.

Our recommended baselines in parts per million are: 350-400 for Ca, 80-90 for K, 80 (Bray II) for P, 50 for Mg, 0.3-3 for Cu, 3-8 for Zn, and 0.5-1.2 for B. These are the levels needed at sowing time. We maintain our soil pH at between 5.1-5.9. We have not encountered any serious problems of pH getting too high for our conifers, but we have substituted NH4SO3 for NH4NO3 several times as a precaution when initial soil pH was over 6.0.

HARDWOODS

Hardwoods represent a situation somewhat different from conifers. Three different elongation patterns are common to different hardwood species seedlings in southern nurseries, but these present no difficulty in scheduling either fertilization or irrigation. The patterns are multiple flushes with each flush terminating in a development of a terminal bud (example *Quercus* spp.); continuous elongation with decreasing nodal length in response to photoperiod but without a terminal bud until late fall (example sweetgum) and continuous elongation but no terminal bud development (example sycamore). The growth patterns are probably similar to different species of hardwood in the central and Rocky Mountain regions.

As distinct as these species growth patterns are, all species can be readily grown using the same preplant soil fertility levels and the same soil moisture guidelines. However, up to 3 to 4 times more nitrogen may be needed to produce competitive hardwood seedlings. It has only been during the 1993 growing season that we have developed technology of studying carbon allocation patterns in many hardwoods comparable to what was done earlier with loblolly pine. Thus our understanding of how hardwood seedlings grow is not yet comparable to loblolly pine. We do, however, have an understanding of hardwood "what" and "when" but need more information to explain "why."

Hardwood seedlings should be much larger than pines — two to four feet or more are desirable for most hardwood species. To obtain these may take from 280 to 500 kg N/H (250 to 450 lbs N/acre) a year. The N should be applied in equal amounts every 10 to 14 days to maintain continuous elongation of the seedlings. Since elongation of all seedlings aren't synchronized this regular scheduling of N must be maintained or erratic seedling canopy will develop where only those in elongation phase will benefit from N and others may prematurely set terminal buds or otherwise cease growing. With oaks, for example, we plan for 4 to 7 flushes before nitrogen fertiliza-

tion is cut off in early September but can essentially stop seedling elongation by eliminating further nitrogen application once the seedlings target size is reached. It is emphasized that with many hardwoods, once elongation is inhibited during the growing season, it is sometimes very difficult to make it resume.

Irrigation is especially critical with hardwoods as they normally use more water than do pines. The watering is still, however, scheduled when the tension meters register 30 to 50 centibars during most of the growing season just as with the conifers. It is especially important that the hardwoods not be in the same field as most of the conifers or overwatering of the conifers or moisture stress in the hardwoods will occur.

It has been much easier to develop effective baselines for the hardwoods because high soil fertility levels and frequent watering does not result in undesirable size seedlings. High soil fertility regimes can be reduced without undesirable growth affects to hardwood seedlings until a desired baseline is obtained. The great benefit of a common baseline is that fields can be readily changed from one species to another without concern to where in the nursery seedlings will be grown.

We are constantly monitoring soil nutrient status and seedling development to make any adjustments that will improve the seedling's quality. We do not consider any part of the developing technology as the ultimate procedure but rather one which can be modified as new information is obtained.

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This study was supported by U.S. Department of Energy Interagency Agreement No. DE-AI09-76SR-00870 and Georgia Forestry Commission Collection Agreement No. 29-303/404.

Woody Plant Selection for Riparian Agroforestry Projects[1]

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Abstract – Riparian buffer strips primarily function to protect and enhance water resources while maintaining a reservoir of plant and animal diversity. In agroforestry practices, riparian buffer strip establishment entails the deliberate planting or management of existing plant species to enhance those qualities important in mitigating nonpoint-source pollution. These systems can provide numerous other benefits; such as enhanced wildlife, wood and other specialty products, and landscape beautification, depending on the diversity and arrangement of the plant materials. Riparian buffer management strategies will necessarily have to take into account plant attributes and interactions that enable these multiple benefits to be reaped. The need to maintain and establish riparian systems is projected to escalate as their ecological and economic roles in the landscape are better documented. This demand will necessitate a supply of diverse, native or locally-adapted shrubs and trees suitable for riparian buffer systems; thus representing a potential new market for nursery producers of conservation planting materials.

AGROFORESTRY: A BEST MANAGEMENT PRACTICE FOR AGRICULTURE

"The American agricultural system is unparalled in its ability to produce food and fiber, providing quality products for both domestic consumption export. Total agricultural production today is over 2 times the level of 1930. Much of this productivity gain has been made possible by improvements in fertilizers and pesticides for crop protection, as well as crop varieties and cropping technologies" (Carey 1991). Unfortunately, we are now having to come to grips with the side effects of these practices. One of the more serious side effects is the "bio-simplification" of the agricultural landscape. With a concomitant loss of ecological integrity and thus sustainability within the agroecosystem, continued and intensified inputs (e.g. fertilizers, pesticides, cultivation) are necessary to maintain production; further exacerbating the deleterious impacts on the system (see discussion in Schoeneberger 1993).

Because of the serious environmental problems associated with intensive agriculture, a movement towards more sustainable agricultural systems is essential and inevitable. AGROFORESTRY is being promoted as means, in concert with other Best Management Practices (BMPs), to couple ecological sustainability with economic stability.

The International Center for Research in Agroforestry (ICRAF) defines agroforestry as "a collective name for land use systems and technologies where woody perennials are deliberately used on the same management unit as agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence". The Center for Semiarid Agroforestry (CSA), established by the USDA-Forest Service with a focus on temperate, semiarid regions, has expanded this definition to the use of WORKING TREES (planting the right tree in the right place for a specific purpose) in agricultural and community ecosystems to protect, conserve, diversify, and sustain vital economic, environmental, human, and natural resources.

Agroforestry includes both **production agroforestry** (growing a tree crop in combination with an agricultural crop to increase the overall productive capacity of the land), and **conservation agroforestry** (working trees in agroecosystems to provide environmental services and multiple benefits; tree products being secondary). Specific agroforestry practices in temperate regions include windbreaks for field, livestock, and farmstead protection; riparian buffer strips; living snowfences; wildlife habitat; fuelwood and fine hardwood plantations; alley cropping; as well as specialty plantings for honey production or aquaculture. Additional community-oriented practices include municipal watershed stabilization, sludge/wastewater disposal, noise abatement, and screening and dust control.

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

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Benefits derived from these plantings include water and air quality, soil conservation, wood products, improved wildlife habitat and additional amenities such as aesthetics and recreation. Tree windbreaks, riparian buffer strips, tree plantations, and other agroforestry practices can play a prominent role in sustainable agricultural systems because they provide year-round and long-term multiple benefits ranging from wood products to environmental services, such as erosion and water quality control.

Successful agroforestry is dependent on having adapted plant material that will flourish in the stressful environments in which they are to be planted. Tree improvement efforts, utilizing a multidisciplinary approach that combines classical tree improvement with ecophysiology, entomology, forest pathology, soil science, and biotechnology, is underway at CSA in cooperation with the University of Nebraska, as well as several other institutions in the Great Plains.

By using a number of different approaches (i.e. molecular genetics of innate and engineered systems), the process of screening and producing stress and pest resistant conservation trees for the Great Plains can potentially be accelerated. Used in conjunction with materials that can be selected from the now mature provenance plantings established throughout the Great Plains in the 1960's and new findings from the USDA Soil Conservation Service's Plant Material Labs, suitable "agroforestry" planting materials should be readily available for propagation and distribution purposes.

NON-POINT SOURCE POLLUTION

Nonpoint source pollution, versus point source pollution, develops over large areas, making identification and mitigation a difficult task. It includes inputs of sediment, nutrients from fertilizers, animal wastes, pesticides, as well as other substances, via runoff and subsurface flow. Nutrients (e.g. nitrate and phosphorus) and sediment are the leading nonpoint source pollutants of concern. However, the current and more sensitive monitoring efforts have identified pesticides (e.g., atrazine) as a growing problem, especially in the Midwest.

The original Clean Water Act of 1972 was amended in 1987 to include programs to specifically regulate nonpoint source pollution from farms, forests, streets, and construction sites. Despite this effort, nonpoint pollution is now thought to account for about 75% of the pollution in our waterways (Benjamin 1993). The massive agricultural conversion of the Great Plains is a prime example of an intensive economic, social and political enterprise that has produced significant nonpoint source pollution from excessive and/or improper grazing, cultivation, and agrichemical usage.

On easily permeable soils where groundwater percolation is the main pathway of pollutant movement, BMPs are necessarily focused on strategic in-field practices that limit input into the groundwater (e.g., better prescribed fertilizer application). In less permeable soils, where lateral flow is the predominant path and/or where storm runoff accounts for the major flush of pollutants from the land to the waterways, **riparian buffer systems,** acting as biological filters between the field and aquatic ecosystems, can be used to mitigate NPS pollution of waterways. Used in concert with in-field BMPs, riparian buffer systems represent a very versatile and effective tool so that **both** economically-reasonable and ecologically-sound agricultural production can be achieved.

Figure 1 – Forested riparian buffer system in the agricultural landscape. Note the linear and fragmented nature of this landscape feature.

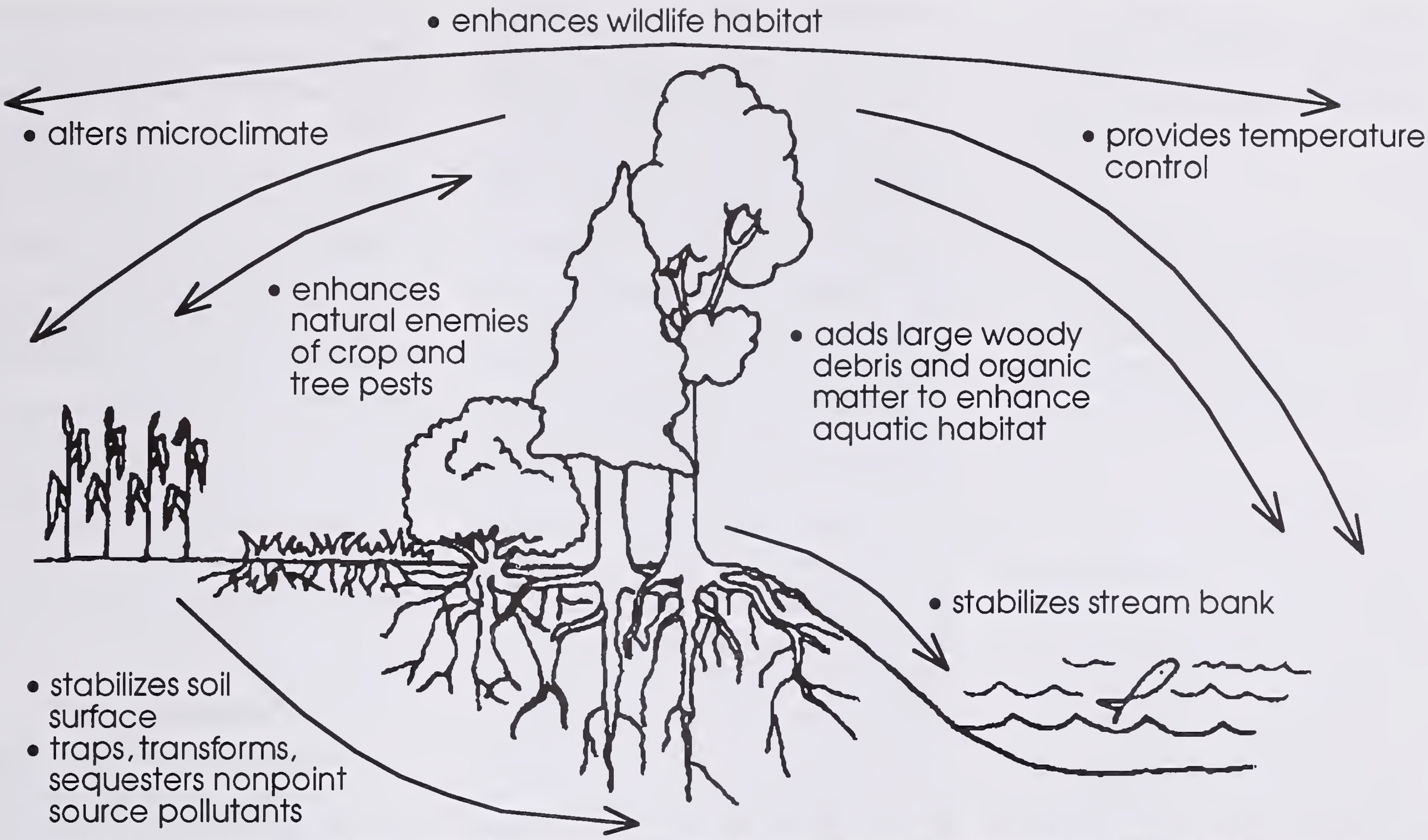

Figure 2 – Multistrata riparian buffer systems behefit the agroecosystem through numerous interactions between the terrestrial and aquatic ecosystems it interfaces with.

RIPARIAN BUFFER SYSTEMS

Riparian systems consist of a narrow band of vegetation immediately adjacent to waterways. The waterway can be a stream, lake, river or other body of water, and can be of a perennial or intermittent nature. The characteristics of the riparian system makes it a distinctive landscape feature due to its fragmented, linear structure (Figure 1).

Riparian forests are considered extremely important because of their role in maintaining water quality. Physically, chemically, and biologically, they function as a "buffer" between adjacent upland terrestrial inputs to adjacent aquatic ecosystem. The trees and associated vegetation trap and filter out the nutrients, pesticides and other nonpoint source pollutants, and create a belowground environment where further sequestration and breakdown of these pollutants can take place via microbial processes. The root systems further serve in the physical stabilization of the stream bank. Smith (1976) reported that bank sediment in vegetated areas (16-18 percent volume of roots) had over 20,000 times more resistance to erosion than comparable bank sediment without vegetation!

Numerous and continuous interactions occur between this fragmented woody system and the adjacent terrestrial and aquatic systems (Figure 2), that can be readily manipulated and capitalized on. In addition to enhanced water quality, properly managed forested riparian buffer systems enhance food and shelter for both terrestrial and aquatic wildlife, increase carbon sequestration, enhance biological control agents (i.e. arthropods) of tree and crop pests, promote stream bank stabilization, and may provide wood products ranging from fuelwood to lumber.

As they become established over time, forested riparian systems are generally characterized by high plant and animal species diversity; making them one of the more dynamic and productive ecosystems. Although these systems comprise only a small percentage of landcover, particularly from the Great Plains westward, their biological and hydrological importance far exceeds the proportion of land cover they comprise. Unfortunately this critical habitat is disappearing at an alarming rate. The tendency in modern agricultural systems is to farm or graze up to the water's edge. Lack of proper management and urban encroachment have further

resulted in loss of riparian systems. These practices have generally resulted in accelerated vegetation, soil and water degradation.

DESIGNING AND MANAGING RIPARIAN BUFFER SYSTEMS FOR MULTIPLE BENEFITS

The establishment of multistrata riparian buffer systems, that consist of a border of forage, shrubs and trees adjacent to a perennial or ephemeral stream, is being examined by a number of federal and state agencies as a BMP to alleviate NPS pollution of our surface and groundwaters (Figure 3). The advantage of the multistrata system is that the grass and shrub components are fast to become established and provide buffering capacity early on; while the trees, which have a much larger capacity to fix nutrients and carbon, become established and effective. The use of multiple strata, also translates into greater flexibility and potential for capitalizing on the many benefits afforded by these systems.

Specifications for generic forested riparian systems are available (Welsch 1991, see Figure 3), but are based predominantly on the research and, thus, conditions existing in the eastern United States (Lowrance et al. 1985). Utilization of this tool in the West and Midwest must be based on a better understanding of the biological, economic, and social constraints of these regions if these systems are to meet the needs of the individual and the watershed.

Several research efforts are underway to develop optimal forested riparian buffer system designs for the Midwest; the three most three most notable efforts being at Iowa State University, University of Iowa, and that recently initiated at CSA in cooperation with the University of Nebraska-Lincoln. The CSA's program encompasses research to optimize the capacity and efficacy of riparian designs, development of BMP guidelines (i.e. species selection and arrangement), demonstrations in rural and community situations, and technology transfer to natural resource professionals.

Specific areas of design and management of riparian buffer systems in the Great Plains that need to be addressed include: 1) guidelines for riparian buffer strip dimensions, especially width,

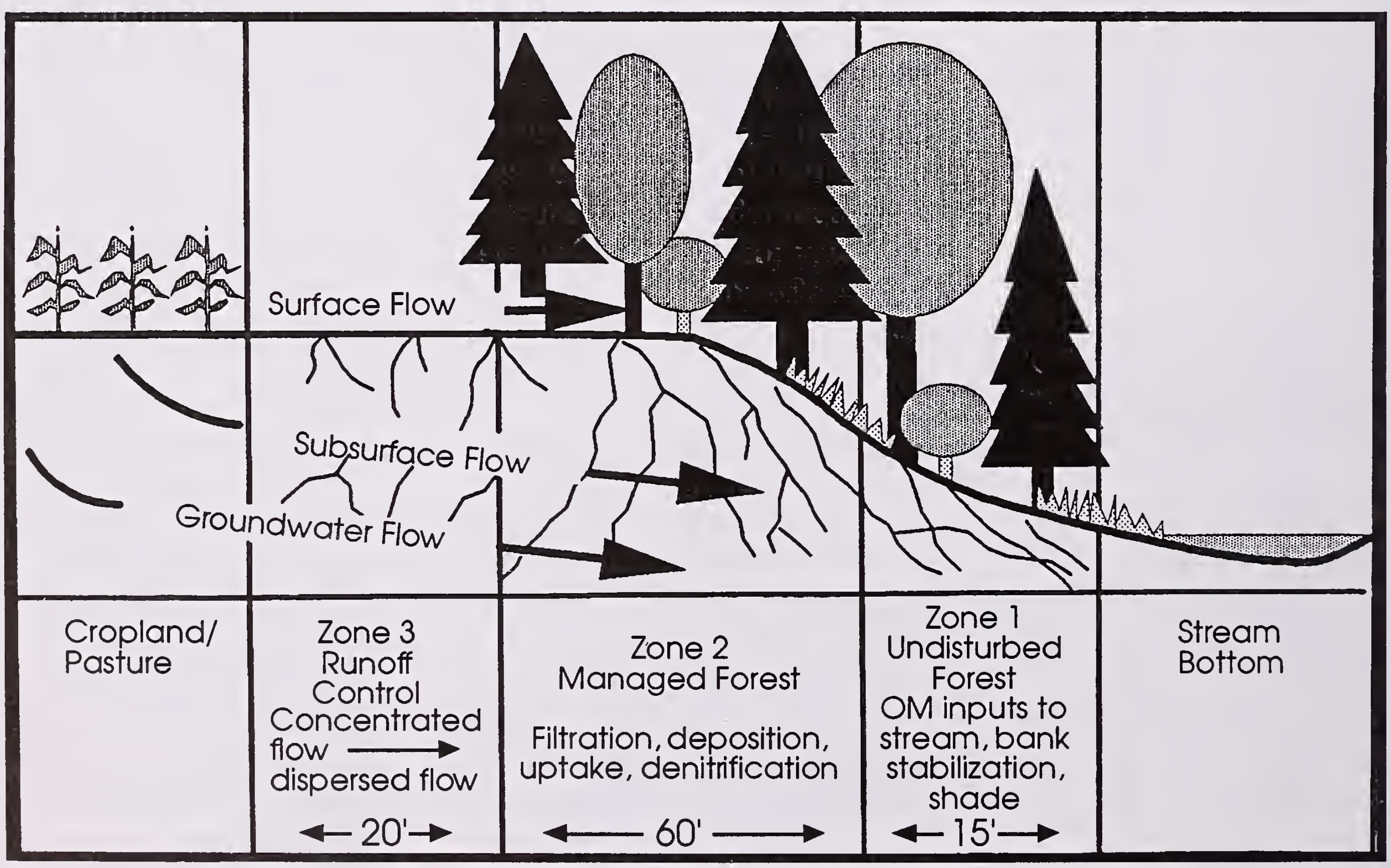

Figure 3 – Generalized multistrata riparian buffer specifications and functions for NPS pollution mitigation in agricultural systems (modified from Welsch, 1991).

2) placement within the watershed with regards to adjacent land-use, other BMP options, and desired environmental endpoints, 3) valuation of amenities derived from these systems by the landowner and by the public, 4) subsequent management of riparian buffer strip to maintain NPS and other functions (i.e. periodic harvesting of plant materials, maintenance of diffuse flow into riparian buffer strip), and 5) the selection and arrangement of plant materials to attain multiple benefits.

SELECTION OF MULTIPURPOSE WOODY PLANTS FOR FORESTED RIPARIAN SYSTEMS

The very nature of riparian systems lends itself well for multipurpose management. As Short (1985) points out though, numerous management goals can be developed for riparian systems but each goal may dictate management policies, strategies, and tactics; and will interact to produce different final products. Multiple use/multiple species management is "doable" today in the sense computers can be used to provide the decision-making framework.

The Soil Conservation Service is in the process of developing their national plant species database – "PLANTS": Plant List of Attributes, Nomenclature, and Taxonomy. PLANTS will provide a standardized botanical data set for use by other software applications (i.e. windbreak design) so that appropriate multispecies/multipurpose plantings can be designed. Unfortunately, the attributes section is still far from being completed. This is particularly true with regards to plant selection for riparian plantings where we are just now defining the criteria we should be looking for in the plant materials. Perkey et al. (1993), provided a listing of tree species and their ability to produce timber, wildlife, aesthetic, and water quality benefits, as well as their relative flood tolerance, but readily admit the categories are subjective and may change as more information becomes available. This document was also developed for the Northern, Central, and Eastern Deciduous Forest Regions, and thus has limited value from the Great Plains westward.

Bottomline, vegetation for riparian forest systems should be native or locally-adapted material, show rapid initial growth, can be economically propagated, and be relatively stress and pest tolerant. However, to optimize the water quality benefits afforded by riparian systems, along with the many other amenities these systems can provide, additional criteria must also be met.

Rooting characteristics may be one of the key selection criteria for riparian buffer strip vegetation. The density and depth of rooting play a big role in the ability of the plant species to intercept NPS subsurface flow, as well as in determining the strength of the stream bank to resist erosion. Fine root turnover provides the majority of carbon input into the belowground system (up to 4 to 5 times as much carbon as contributed by aboveground litter), thus influencing the capacity of the system to microbially process the NPS pollutants. Denitrification, a microbial process whereby excess nitrate is transformed to gaseous nitrogen and thereby released to the atmosphere before it can enter the waterway, is dependent on this C input.

Several of the other belowground plant considerations are not that easily discerned but do play a major role in how a riparian system operates. For instance, we know different species of plants influence the quality and quantity of microbial activity, much of which may play a role in filtering NPS pollutants. More importantly, we know by selecting and interplanting a mixture of species, the diversity and quantity of these microbial functions may be further enhanced (Bopaiah and Shetty 1991).

Because trees and other woody perennials are effective nutrient traps, they provide a longer-termed sequestration of nutrients and other chemicals. In selecting plants materials for riparian buffer strips, specifically for this capability to trap NPS pollutants, consideration must be with regards to the specific nutrient uptake by each plant species through time. The capacity to sequester nutrients and chemicals varies with species (i.e., oak requires more nitrogen than spruce or pine) and age (i.e., nutrient uptake being most rapid in young trees). Thus the selection criteria will need to include the inherent capability of the plant to take up nutrients, as well as what management of that species will need to take place to maintain a useful level of uptake.

Selection of plant species for purposes of enhancing wildlife habitat, along with the water quality aspects, will be dependent on the specific group being targeted. While proper placement of riparian vegetation to control streamwater temperature for fish habitat is well understood, selection of the specific plant species for enhancement of fisheries is not as well known. A recent article by Sweeney (1993) points out that the selection of plant species in the riparian area can dramatically influence the fisheries habitat by altering the quality of food available to the macroinvertebrate populations that the fish depend on for food. His studies indicate a **mixed, native** species composition in streamside areas will support a wider variety of macroinvertebrates than a monoculture or non-native woody perennial composition is capable of supporting.

Other considerations that will need to be taken into account when selecting species for forested riparian systems include structural, disease, and allelopathic limitations. Depending on the specific placement of a riparian system within the agroecosystem and the nature of the waterway, selection of short-statured woody plants may be necessary to avoid unwanted microclimate shifts via the shelterbelt effect of the planting on adjacent crops and/or to avoid streambank "de"stabilization. Disease considerations that go beyond the use of stress and pest resistant genotypes must also include avoidance of species that serve as alternate hosts for disease organisms. For example, you would want to avoid planting juniper species near apples orchards as they serve as the alternate host for cedar-apple rust.

In considering allelopathic interactions in woody plant mixtures, both advantageous to disadvantagous interactions are possible. By proper selection of plant materials, undesirable weeds may be controlled through allelopathy, such as that encountered with the use of *Leucena leucocephala* and *Abies balsamea.* Unfortunately, the allelopathic inhibition of plant establishment may suppress establishment of desirable plants, such as that observed with black walnut.

Bottomline, selection of woody plant vegetation for riparian buffer strips in the Great Plains will need to take into account the following criteria: soil/site limitations; rooting depth; nutrient uptake and cycling; pesticide, pest, and abiotic stress tolerances; terrestrial and aquatic wildlife values, as well as value for aesthetics, recreation, and wood products; and those other considerations that determine the species ability to mitigate NPS pollution and provide other amenities.

The impetus for "WORKING" forested riparian buffer systems will only continue to escalate as the NPS pollution of our waterways becomes elucidated. The impetus for having these systems was perhaps no more poignantly illustrated than by the impacts of the 1993 floods that rampaged the midwest. More information will be needed to develop the necessary guidelines required for forested riparian establishment and management. But more importantly, a diversity of suitable plant material will need to be readily available to capture this window of opportunity to implement a "WORKING TREE" strategy.

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Progress Report on Propagation of *Juniperus* for Conservation Planting[1]

A.M. Wagner, J.G. Mexal, J.T. Harrington and J.T Fisher[2]

Abstract – Rocky mountain juniper and eastern red cedar are important species for conservation plantings in the Intermountain region. Nurseries often have difficulty in meeting the demand for junipers because of slow and variable seed germination and a long production cycle. This project was initiated in part to examine an alternative production method using vegetative propagation. The project has two goals, to improve the planting stock available and to shorten the production cycle by vegetative propagation. For improving planting stock, 12 year old select plants from a regionwide planting. Studies examining season of collection and root-promoting growth regulator effects on rooting are in progress. The study for the second phase of the project involves looking at rooting of cuttings from young stock plants (less than three years) for transplanting into bareroot nurseries and is still in progress.

INTRODUCTION

Eastern red cedar (*Juniperus virginiana* L.) and Rocky Mountain juniper (*J. scopulorum* Sarg.) are important conservation species in the Intermountain region. They are essential components in windbreaks, living snow fences and wildlife plantings. In the 13 states that constitute this region (AZ, CO, KS, MT, ND, NE, NM, NV, OK, SD, TX, UT, WY) over 2 million juniper seedlings are produced each year (Anon. 1989). The increased demand for conservation plantings has resulted in an increased demand for juniper seedlings as well. In 1992, state and federal nurseries in this region supplied only 50% of the demand for junipers. This constitutes a shortage of over 2 million seedlings. This deficit will likely increase as demand for conservation plantings increases.

Currently, the production of juniper both as containerized and bareroot seedlings, is exclusively by sexual propagation. Seed requires two years on the tree to mature. Furthermore, seedling production in the nursery can require up to three years if seeding occurs in the Fall. Thus, the process from flower primordia initiation to transplanting can require five years. The major difficulty in juniper production is achieving consistent emergence following sowing. Germination rates of 20-50% are not uncommon (Rietveld 1989).

Another approach to producing juniper planting stock is through asexual or vegetative propagation. This approach has several advantages and is the exclusive technique used in the propagation of ornamental junipers. First, vegetative propagation permits the use of elite genotypes developed by the USDA Forest Service tree improvement program. Van Haverbeke and King (1990) identified superior selections for the Intermountain region. These selections include male clones preferred for some windbreak plantings, disease resistant clones, and clones selected for superior survival and growth in the region.

The second advantage is vegetative propagation could reduce the time required to produce bareroot nursery stock. The current scheme requires 2-3 years to produce plantable stock depending on the nursery. It is conceivable, based on the ornamental nursery industry, that plantable stock could be produced in one year using vegetative propagation.

The third advantage is the possibility of improved management and reduced costs associated with producing plant material. Vegetative propagation would reduce or eliminate inadequate utilization of bed space through poor germination or excessive stocking. It could eliminate thinning costs, reduce transplant costs, and reduce losses to inclement weather. Through improved management practices, it is conceivable that the current 50% shortfall in juniper seedlings could be eliminated

[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

[2] *A.M. Wagner and J.T. Harrington are Post-doctoral researcher and Assistant Professor, respectively, at the Mora Research Center, New Mexico State University, Mora, NM. J.G. Mexal and J.T. Fisher are Professors, Department of Agronomy and Horticulture, New Mexico State University, Las Cruces, NM.*

with little increase in production area or costs.

OBJECTIVES

The objectives of this project are to develop techniques for vegetative propagation of older juniper to allow for genetic improvement of planting stock. In addition, to develop techniques to shorten the production cycle for junipers for conservation nurseries.

MATERIALS AND METHODS

Improvement of Planting Stock

The junipers planted as part of the GP-13 trial throughout the Great Plains were used in the experiments for improving planting stock. The plantations were established in 1980-1981, and include the Horning State Farm, NE, the Los Lunas Experiment Station, NM, and the Mandan, ND planting. The Rocky Mountain juniper did not establish and survive well at the Nebraska site, so only eastern red cedar could be sampled from that location. Both species could be sampled from the other locations. A total of 13 eastern red cedar seed sources (45 genotypes) and 14 Rocky Mountain juniper seed sources (49 genotypes) are being tested in all the studies in this phase of the project.

Timing of collection of cuttings

The purpose of this study was to determine the optimum collection time for rooting stem cuttings. Four collection times were selected to evaluate seasonal differences in rooting potential. Cuttings are collected in February/March, March/April, June, October 1993 and January 1994. Cuttings are collected in the field, placed in a cooler and processed within 48 hours of collection. All cuttings are taken from the lower half of the crown.

The study was initiated in February 1993 with collections of eastern red cedar from the Horning State Farm, NE GP-13 juniper planting. Collections from this site are February 1993, March 1993, June 1993, October 1993 and December 1993. Six seed sources and 4 half-sib trees are sampled from each source. Sampling involves 10 cuttings from each tree for each collection.

Rocky Mountain juniper is sampled from the Los Lunas, NM GP-13 juniper planting. Seven seed sources and 4 half-sib trees from each source are sampled. Ten cuttings from each tree for each collection are sampled. Collections from this site are made in March 1993, April 1993, June 1993, October 1993 and December 1993.

In addition, three eastern red cedar and three Rocky Mountain juniper seed sources are being sampled from the Mandan, ND GP-13 planting. Three trees from each seed source are sampled with 10 cuttings from each tree each collection. Collections from this site are July 1993, October 1993, December 1993 and March 1994.

Cutting type and position

The purpose of this study was to determine if cutting type and location on stock plant are related to rooting potential. There are two types of cuttings present on juniper trees, the first is the recently expanded shoot with small, flat needles often referred to as juvenile. The second type is the mature shoot with open, appressed needles. Three locations on the tree were defined for this study, the upper one-third of the crown, the middle one-third of the crown and the lower one-third of the crown.

This study was initiated in February with two eastern red cedar trees sampled from Nebraska and in March with two Rocky Mountain juniper trees sampled from New Mexico. From each crown location and cutting type 15 cuttings were sampled for a total of 90 cuttings per tree.

Plant Growth Regulator Application

The purpose of this study was to determine the optimum level of root promoting growth regulator and see if level changes with season of collection of cuttings. The same dates were used for collection as with the timing of collection study. All cuttings were from the Los Lunas plantation and both eastern red cedar and Rocky Mountain juniper were sampled. Four seed sources and three trees per source for each species were sampled. Twenty cuttings were sampled from each tree, with five cuttings for each plant growth regulator treatment. The treatments included 10,000 ppm IBA + 5000 ppm NAA, 5000 ppm IBA + 2500 ppm NAA, 3333 ppm IBA + 1667 NAA, all using Dip'n Grow® (Astoria-Pacific, Clackamas, OR) liquid as a quick

dip, and 8000 ppm IBA applied as talc using Hormodin 3® (MSD-AGVET, Rahway, NJ)[3].

GENERAL PROPAGATION METHODS

Cuttings were treated with 5000 ppm IBA + 2500 ppm NAA as a liquid quick dip (1:1 Dip'n Grow®), except for those cuttings in the plant growth regulator study (Henry et al. 1992). Cuttings are placed in a 1:1:1 (v:v:v) mixture of peat:perlite: vermiculite in 164 ml Ray Leach "Cone-tainer" C-10 cells. Cuttings were placed on the propagation bench for 16 weeks with bottom heat at 18°C. Air temperatures in the greenhouse ranged from 7.2°C to 25.5°C. Heating began at 7.2°C and cooling at 10°C (Russell et al. 1990). An overhead mist system applied mist to the cuttings 12 times during daylight hours, the bench was enclosed in a fabric tent which was kept moist by overhead mist. Periodically the cuttings were hand-watered to maintain proper levels of moisture in the rooting media. Applications of fungicide and insecticide were made as needed. After 16 weeks the cuttings were removed and evaluated. Rooted cuttings were potted for future use as mother plants. Cuttings with well-developed callus were replaced on the bench for potential root development.

Reduction of production cycle

The purpose of this study was to examine the effects of rooting volume and container diameter on rooting of cuttings. Also, to determine length of time needed to fill rooting volume for transplant and/or outplanting. The study used eight container sizes ranging from 39 ml to 164 ml (Table 1).

Eastern red cedar cuttings were taken from 2-0 bareroot stock plants and from 9 month container-grown stock plants. Rocky Mountain juniper cuttings were taken from container-grown stock plants. Cuttings ranged from 3 cm to 12 cm. Containers were filled with 1:1:1 peat:perlite:vermiculite (v:v:v). Cuttings were taken from stock plants and immediately treated with 1333 ppm IBA + 667 ppm NAA liquid quick dip (Dip'n Grow®) and placed in the rooting environment (Major and Grossnickle 1990). For each species 20 cuttings per container type were stuck for evaluation with three replications. The remaining cells in the containers were filled with cuttings to provide a buffer zone around the cuttings in the study.

The rooting bench had bottom heat (18°C) and an overhead mist system which came on twice hourly for 4 sec during daylight hours. Shade cloth (63%) was placed above the bench system. The greenhouse conditions were as described above. The study was initiated in April, 1993. Cuttings will be evaluated as 50% of the cells show roots out the bottom. Time until roots appear at base will be recorded for each container type and species. Rooted cuttings will be evaluated on root number, total root length of primary roots, root branching, whether or not the plug was full, and shoot length.

[3]*Mention of specific compounds does not constitute an endorsement of those compounds.*

Container	Volume (ml)	Diameter (cm)	Depth (cm)	Number/m
First Choice Block 2A	39	2.5	11	1109
Ropack Multi-Pot 5-104	49	2.5 x 3.2	9	1206
First Choice Block 4	65	3.1	12.7	764
Ray Leach "Conetainer" C-4	66	2.5	16	1076
First Choice Block 5	77	3.1	15	667
Ropack Multi-Pot 3-96	98	3.8	12	441
Ray Leach "Conetainer" C-7	115	3.8	14	528
Ray Leach "Conetainer" C-10	164	3.8	21	528

Table 1. Container types and sizes used in study. (All containers from Stuewe and Sons, Inc. Corvallis, OR.)

RESULTS

Timing of collection of cuttings

Cuttings from the first two collections in this study were evaluated June 1993 and August 1993. None of the eastern red cedar cuttings from the first collection in February rooted and only two cuttings (of 240) rooted from the second collection in March. Three Rocky Mountain juniper cuttings rooted (of 280) from the first collection in March and only two cuttings rooted from the second collection in April. However, with the Rocky Mountain juniper, all the rooted cuttings were from the same seed source. More of the cuttings callused from the first collection than from the second collection for both species.

Cutting type and position

Cuttings were evaluated June, 1993 for rooting and callusing. Only three eastern red cedar cuttings rooted out of 180 cuttings sampled. Thirty eight of the cuttings developed callus. None of the Rocky Mountain juniper cuttings rooted and 29 of 180 cuttings showed callus development. Because of the poor rooting response, no conclusions could be made about cutting position and type and rooting. However, all of the eastern red cedar cuttings with callus were the juvenile type shoot cuttings and 90% of the Rocky Mountain juniper cuttings with callus development were the juvenile type shoot cuttings.

Plant Growth Regulator Application

Cuttings from the April collection were evaluated in August 1993. Of 240 eastern red cedar cuttings, 39 rooted (16%) and 8 of 240 (3%) Rocky Mountain juniper cuttings rooted. Cuttings treated with the full strength Dip'N Grow (10,000 ppm IBA + 5000 ppm NAA) showed best rooting for eastern red cedar (Figure 1). The Rocky Mountain juniper cuttings treated with 5000 ppm IBA + 2500 ppm NAA rooted slightly better than cuttings treated with full strength Dip'N Grow (Figure 1). Cuttings from the Texas and Nebraska eastern red cedar seed sources rooted more frequently than cuttings from the other two seed sources sampled (Oklahoma and Kansas).

Reduction of production cycle

This study has not been fully evaluated. Based on appearance of roots from the base of the containers, eastern red cedar cuttings appear to be rooting faster than the Rocky Mountain juniper cuttings (Figure 2). Cell volume appears to influence rate of appearance of roots from the base of the container more than cell depth.

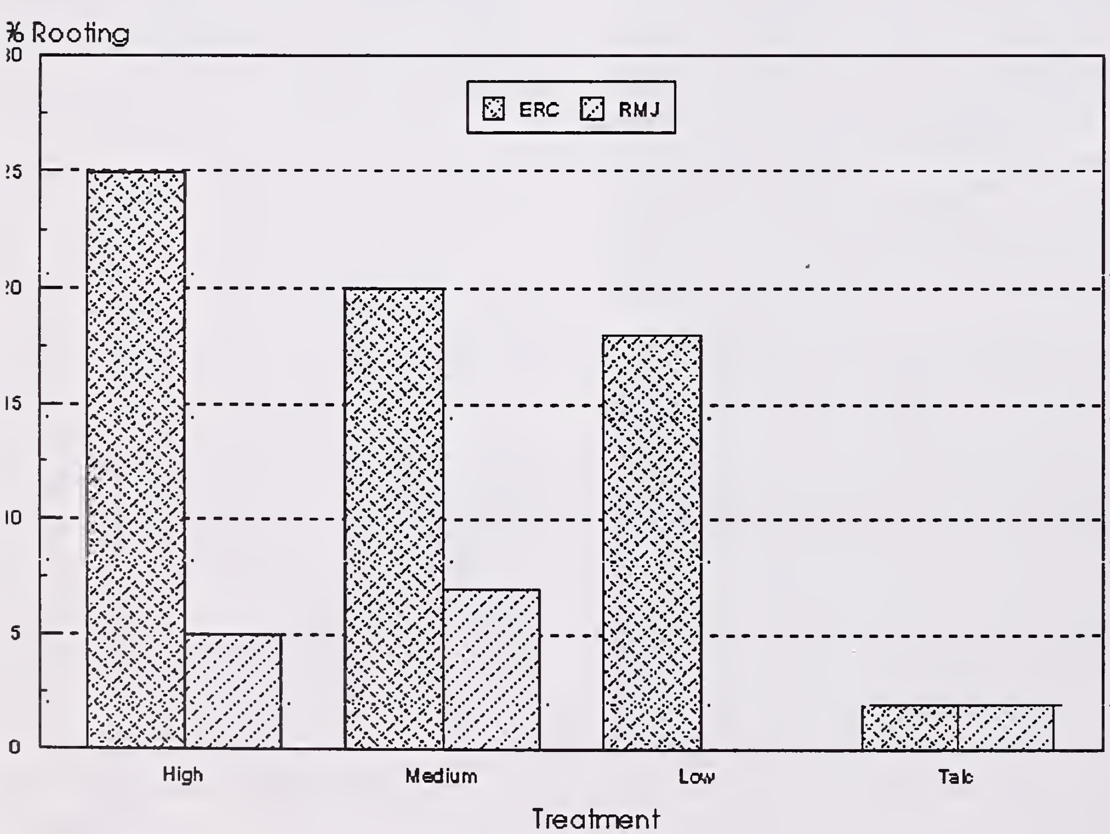

Figure 1 – Rooting of mature eastern red cedar and Rocky Mountain juniper cuttings collected in April, 1993 and treated with various levels of plant growth regulators. High = 10,000 ppm IBA/5,000 ppm NAA; Medium = 5,000 ppm IBA/ 2,500 ppm NAA; Low = 3,333 ppm IBA /1,667 ppm NAA; Talc = 8,000 ppm IBA powder.

DISCUSSION

Although most of the experiments discussed are still in progress, the preliminary results are encouraging. While rooting for cuttings from the older stock plants is low, results of the growth regulator study indicate rooting is possible for both spe-

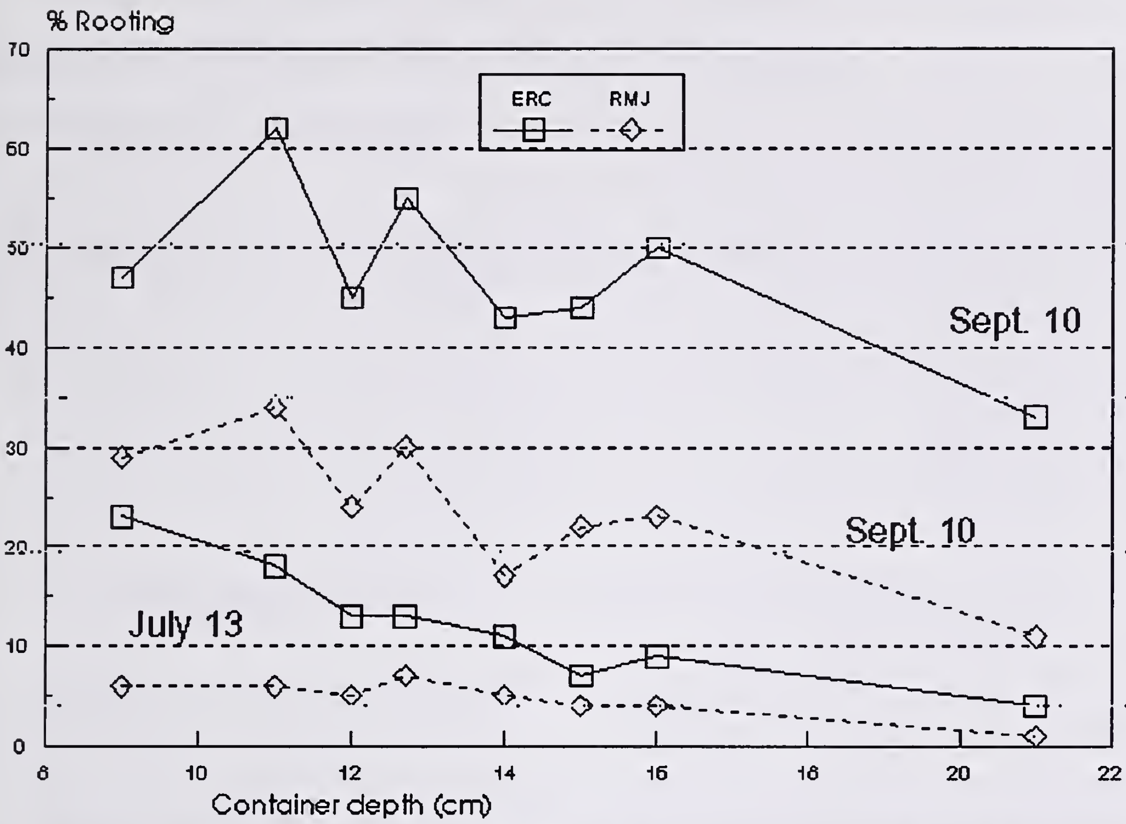

Figure 2 – Percentage of eastern red cedar and Rocky Mountain juniper cuttings with roots appearing from base of container over time.

cies. In addition, rooting is expected to be greater of cuttings collected in the fall and/or winter. The initial results of the container study indicate that rooting of cuttings from young stock plants holds great potential for reducing the production cycle of junipers. The eastern red cedar is rooting faster than the Rocky Mountain juniper cuttings. However, this difference may be explained by difference in conditions of the stock plants. The eastern red cedar stock plants had been hardened off or were bareroot transplants recently removed from storage. The Rocky Mountain juniper was from actively growing greenhouse stock plants. These differences will be examined in future experiments.

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Funding provided by USDA Forest Service, Intermountain Conservation Nursery Association and International Arid Lands Consortium Grants.

Timing of Collection and Seed Source Affects Rooting of White Fir Stem Cuttings[1]

A.M. Wagner, J.T. Harrington and J.T. Fisher[2]

Abstract – The importance of white fir as a Christmas tree and its variation in color and form make it a good candidate for clonal development. This experiment examined the effect of timing of collection on rooting stem cuttings. In addition, the effect of seed source of stock plants on rooting of stem cuttings was examined. Nine weekly collections were made from the beginning of December to the end of January, 1991 and nine seed sources were sampled. The best rooting was seen in cuttings collected January 7. Three northern New Mexico seed sources rooted better than the other sources (60% across all collection dates). Root characteristics were affected by timing of collection and seed source of stock plant.

INTRODUCTION

White fir (*Abies concolor*) is native to New Mexico and the southern Rocky Mountains and is an important Christmas tree species. There is variation in needle length, needle color and crown density which influence the appearance of the tree. Needle length can range from two cm to six cm and color ranges from silver to dark green. These characteristics are important in determining suitability for Christmas tree production. Once desirable characteristics are identified, clonal development is needed to capture these variations.

Asexual propagation by stem cuttings is one means of capturing the variation in white fir. However, very little work has been done on vegetative propagation of white fir. While certain aspects of propagation of conifers are similar, developing a propagation program specifically for white fir is necessary. Important factors for vegetative propagation include timing of collection which is influenced by environmental conditions.

Seasonal variation in rooting capacity is a well known. Previous experience with white fir as well as published reports suggest that timing of collection could be critical to rooting success of cuttings (Moe and Andersen 1988, Hartmann and Kester 1983). Most conifers root best in the winter months after some chilling of the set bud has occurred and before budbreak in the spring. Research on Douglas-fir has shown rooting is related to bud dormancy (Bhella and Roberts 1975, Roberts et al. 1974). In Douglas-fir rooting was low during pre- and true dormancy, and highest during post-dormancy (August through December). Propagation for other conifers grown in northern New Mexico is best in December or January and it seemed possible that white fir would root best during that time also (Wagner et al. 1989, Schaefer 1989).

In addition, it is well-established that rooting potential varies greatly between families and even within families. Screening of potential clones with desirable characteristics for rooting capacity is necessary in developing a program of improvement for white fir. A provenance study established at the Mora Research Center allowed for screening of a wide range of genotypes and seed sources for rooting potential.

OBJECTIVES

The objectives of this experiment were to develop techniques for stem cutting propagation of white fir to allow clonal development by looking at timing of collection and seed source variation in rooting.

MATERIALS AND METHODS

The white fir stock plants were field planted in 1978 as a provenance test, and hedged to 1 m in 1989. Weekly collections were

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[1]*Poster presented at the Combined Northeast Area and Intermountain Forest Nursery Association Meeting, St. Louis, MO, August 2-5, 1993.*

[2]*A.M. Wagner and J.T. Harrington are Post-doctoral researcher and Assistant Professor, respectively, at the Mora Research Center, New Mexico State University, Mora, NM. J.T. Fisher is Professor, Department of Agronomy and Horticulture, New Mexico State University, Las Cruces, NM.*

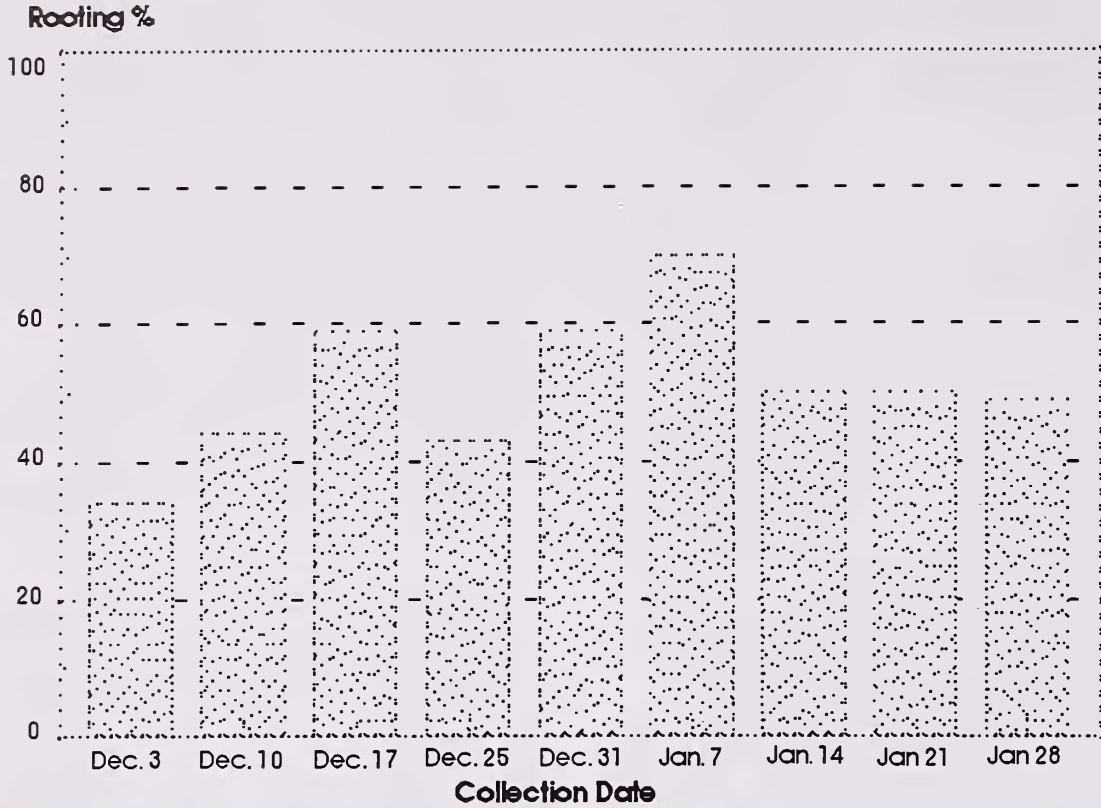

Figure 1. Rooting percent of white fir stem cuttings by collection date.

made from December 1, 1990 to January 30, 1991 (a total of nine collections). Stock plants from nine New Mexico seed sources were selected with five trees sampled from each seed source. The seed sources ranged from southern New Mexico to northern New Mexico origins. For each collection date, five cuttings were taken from each stock plant. All cuttings were taken from the mid-section of the hedged trees, with all cuttings being approximately the same length.

The cuttings were processed immediately after collection. Processing included recutting to 12.5 cm, removal of the needles from the lower 2.5 cm of the cutting and a quick dip into a liquid root promoting plant growth regulator. The quick dip was a solution of 1250 ppm indolebutyric acid (IBA) and 1250 ppm napthalenacetic acid (NAA). Cuttings were placed into Ray Leach C-10 "Cone-tainers"™ (Stuewe and Sons Inc., Corvallis, OR) filled with a 1:1 vermiculite: perlite mix (v:v).

Cuttings were placed onto a propagation bench with bottom heat (18°C) and an overhead moving boom mist. Mist was applied hourly during daylight hours. The entire bench is enclosed in a fabric tent kept wet with overhead mist. Greenhouse temperatures were 20 to 25°C. After 16 weeks the cuttings were evaluated for rooting. In addition to rooting, root number, root length, root branching and shoot elongation/budbreak was evaluated. Root number was the number of roots originating at the base of the cutting. Root length was a measure of the longest root length. Root branching was a code from 0 to 3 of degree of branch root development with 0 being no branch roots present, to 3 highly developed branch roots.

The experimental design was a split plot design. the whole plot treatment design was a completely randomized block (source) with collection date as the split factor. Statistical analyses were done using analysis of variance techniques (GLM, SAS Institute, 1989). Discrete data were analyzed using categorical model

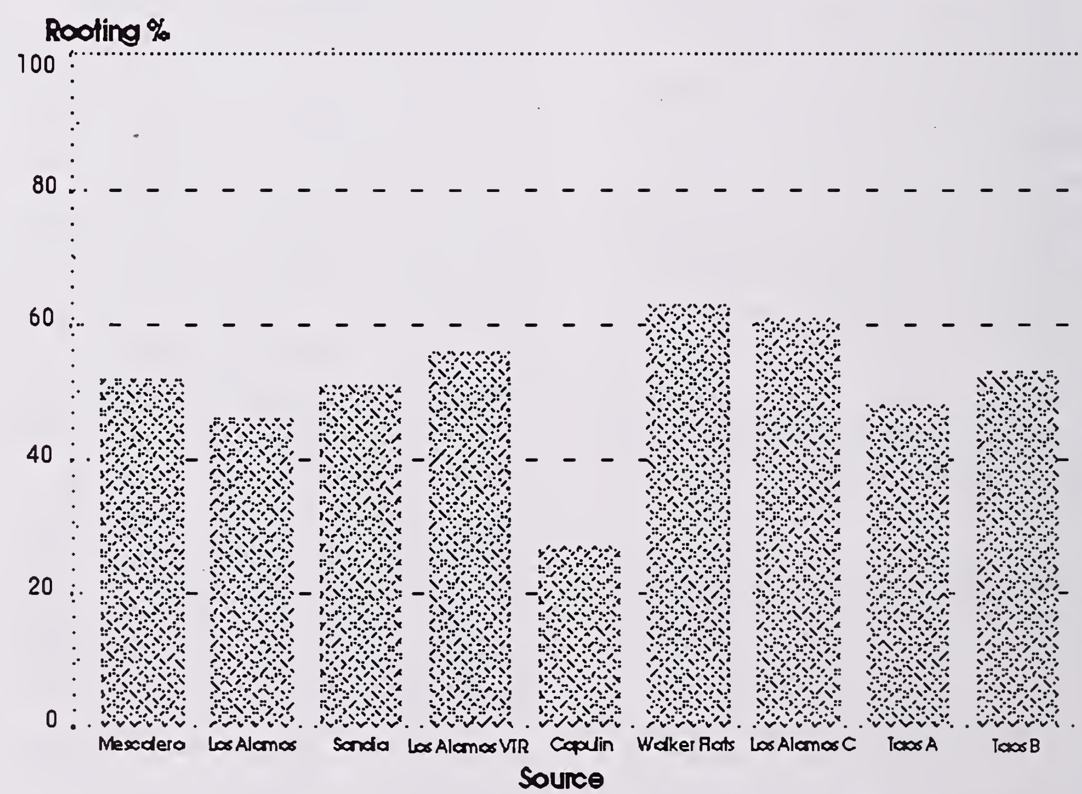

Figure 2. Rooting percent of white fir stem cuttings by seed sources of stock plants.

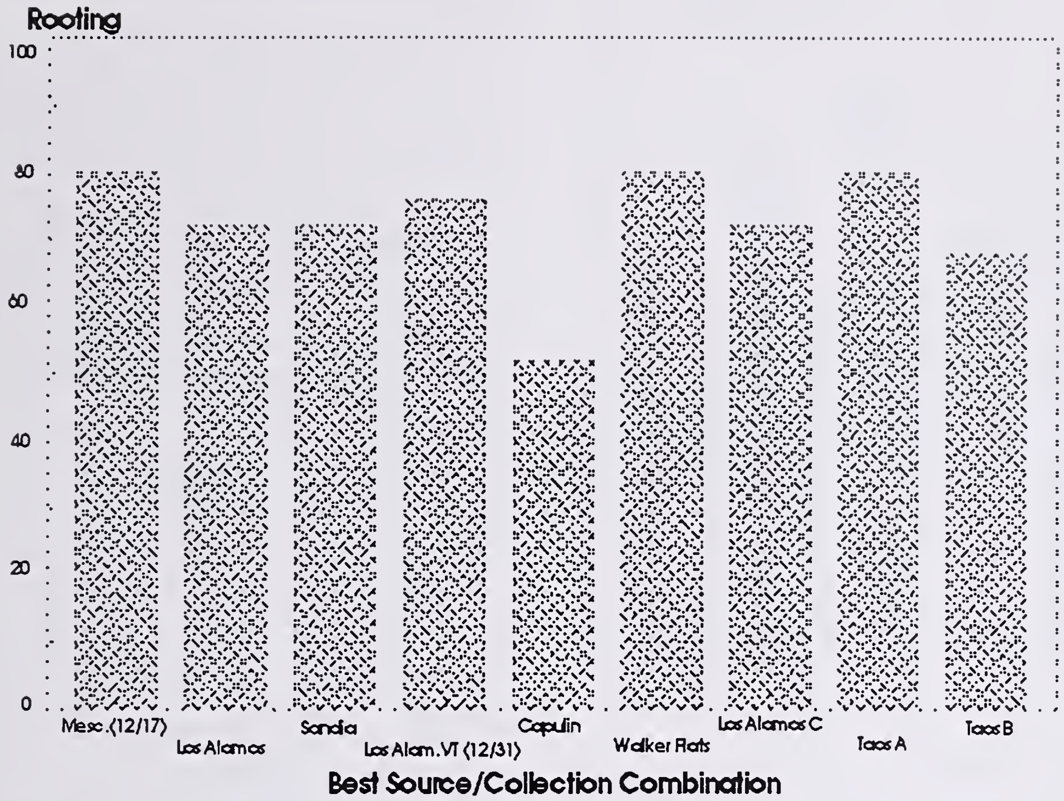

Figure 3. Root number, length and branching of rooted white fir stem cuttings by collection date.

analysis (chi-square test, CATMOD, SAS Institute, 1989).

RESULTS

Overall rooting was fairly high with the best collection date and seed source rooting at 80%. Rooting varied by collection date and seed source. The best collection date over all sources was January 7 with 70% rooting, the worst rooting was seen from cuttings collected December 3 with 34% rooting (Figure 1).

The analysis suggests that rooting, when determined by collection date is a quadratic function, in that rooting is low at the beginning, peaks more or less in the middle and then drops off. By seed source, collection date was significant for all but two sources (Los Alamos C and Taos B). Los Alamos C showed a peak at December 31, but also showed high rooting for the last two collection dates. Taos B rooting peaked at the January 7 collection, showed a drop for the January 14 collection and then increased rooting. Most sources showed peak rooting on the January 7 collection date (Figure 3). The southernmost seed source (Mescalero) showed peak rooting for the December 17 collection, and the Los Alamos VTR source showed peak rooting from the December 31 collection.

As expected, seed source of stock plants was important in rooting potential. Rooting for the nine sources ranged from 27% to 62% across all collections (Figure 2). The best sources for rooting were the Walker Flats, Los Alamos C and Los Alamos VTR sources, all northern New Mexico sources. There were four sources with rooting levels greater than 50% across all collections and four sources with rooting levels from 46% to 50%. Only one source showed very low rooting responses. Tree to tree variation was also important in determining rooting success. Overall rooting of cuttings by tree ranged from 2% to 87%. Most of the trees fell between 50% and 87% of the

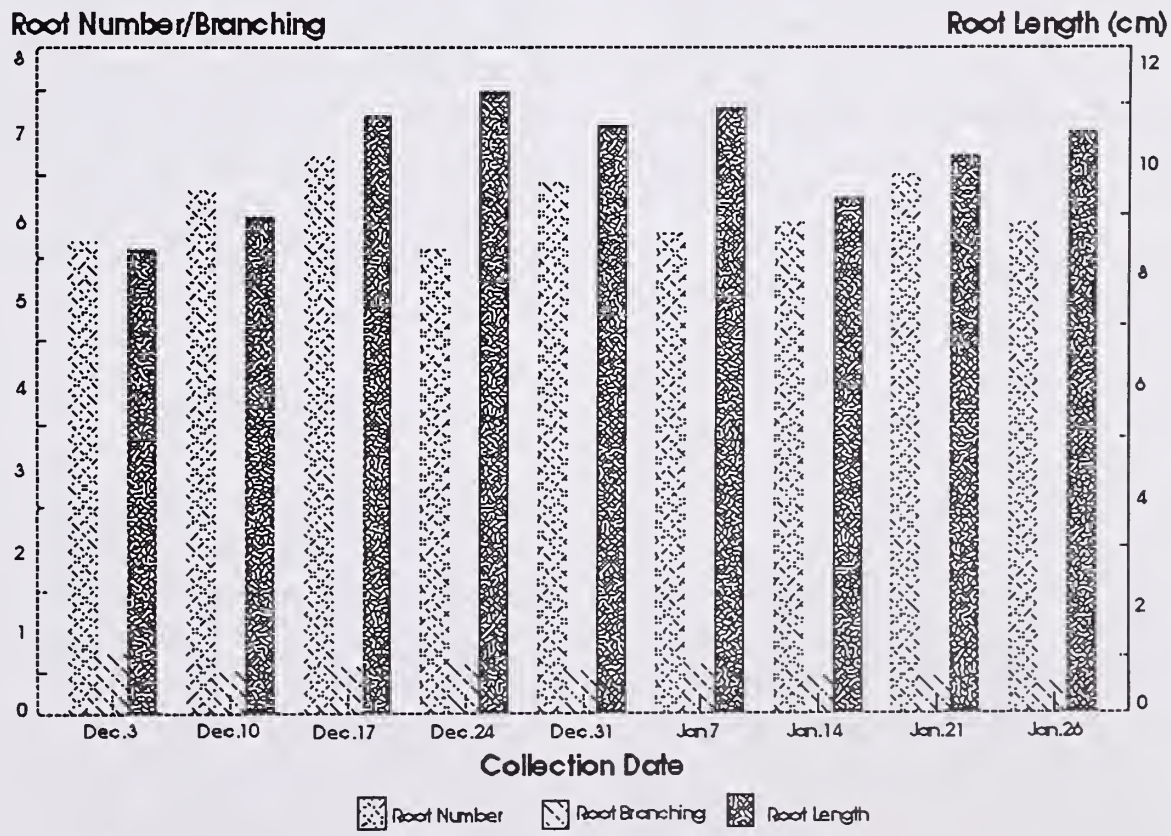

Figure 4. Root number, length and branching of rooted white fir stem cuttings by seed sources of stock plants.

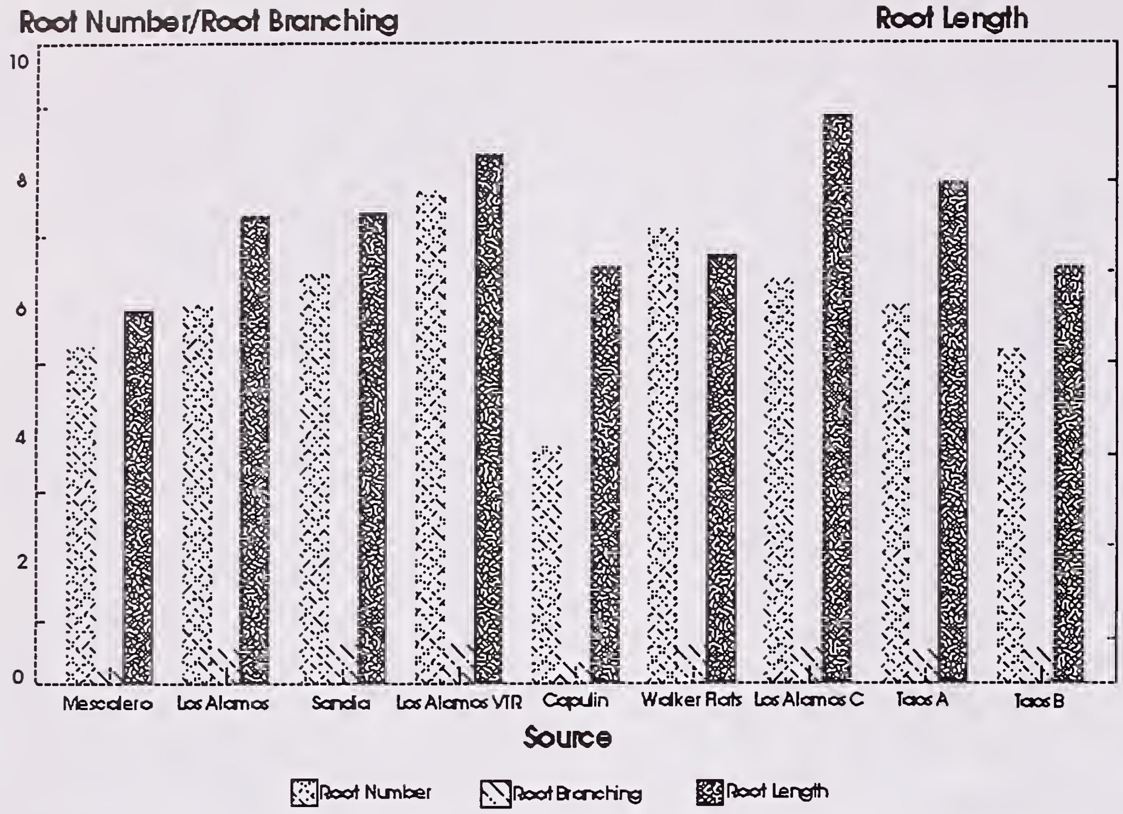

Figure 5. Rooting of white fir stem cuttings by seed source for best collection date of that source. Collection date is January 7 unless otherwise noted.

cuttings rooting. Of the 45 trees sampled, 53% showed 100% rooting for at least one collection date.

Root characteristics were analyzed without those cuttings not rooted. There was no interaction between collection date, source and root characteristics. The highest values for root characteristics did not necessarily correspond with the highest rooting collection date (Figure 4). Root number was not significantly affected by collection date ($p > 0.1$). Root length was significantly affected by collection date ($p = 0.0002$). The greatest root length was seen from cuttings taken December 24 and January. Root branching was also significantly affected by collection date ($p = 0.0029$). Cuttings collected December 3 and January 7 showed the highest root branching.

All the root characteristics measured were significantly affected by seed source of stock plants ($p = 0.0001$). The highest values for all three root characteristics measured were seen in the three best rooting sources (Figure 5). Mean root number ranged from 5.24 to 7.69 roots per cutting. Mean root length ranged from 8.16 cm to 12.39 cm, and mean root branching ranged from .19 to .62.

DISCUSSION

The results of this experiment indicate that white fir is adaptable to a stem cutting propagation program. First year results (one year past hedging) were acceptable. However, it is clear that timing of collection is critical to success as seen in the range of rooting success from 34% to 70% over nine weeks. Determining the optimum time for collection is critical to successful rooting. Not only does timing of collection affect rooting but it also influences root development as evaluated by root length and root branching but in this study not root number. Combining the two factors to obtain acceptable rooting and root development is important.

The highest rooting levels were seen from the January 7 collection and collections from December 17 and December 31 also rooted well. The drop in rooting seen for the December 24 collection corresponds with a severe cold spell (1 week below -20°C). The severe cold may have adversely affected rooting of cuttings collected during that period. Although a follow-up study is necessary, rooting of white fir stem cuttings appears highest from mid-December to early January.

Seed source and tree within seed source are also important factors in rooting success. Most of the sources rooted fairly well and could easily be included in a propagation program. Although some of the sources did not root as well overall, it does appear as if the poor rooters have a narrower window for optimum rooting success than do the better rooting sources. All seed sources had at least one tree which rooted fairly well which will allow for including at least some trees from all seed sources in a propagation program.

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Tree Seedling Distribution Program – G. White State Forest Nursery[1]

Dena Biram[2]

Abstract – In 1981, seedling orders were entered here at the nursery on one Personal Computer and the data transmitted to Jefferson City for processing. The same system was used until October 1992. Because of the large number of seedling orders handled and the time lapse involved with tracking inventory and financial transactions when information is processed in two different locations, a project was under taken to allow for all aspects of the seedling ordering system to be conducted at the nursery. The backbone of this system is an IBM AS/400 computer with a high speed printer capable of printer bar codes. The new system allows us to process over 13,000 orders annually. This is a brief description of the system capabilities.

Until the fall of 1992 all seedling orders were entered on a personal computer located at the nursery, but processed on the mainframe computer in the Department Headquarters in Jefferson City. It was felt that the operation could be handled more efficiently with fewer errors if it could be done entirely at the nursery. So between 1991 and 1992 shipping seasons, hardware was purchased and software developed that would allow this to happen.

Order forms are released to the general public in November and begin arriving back to the nursery at a rate of several hundred per day. The orders are stamped in numerical order as we receive them. Other than State land orders, seedling requests are filled on a first come, first serve basis. (figure 1)

When we enter orders, the zip code is the first item entered. The system will automatically bring up the town, county and area code. The name and address is then entered. This information is used at least three more times before we are finished with this order. After the name and address the shipping month is entered. The final item to be entered is the species and quantities requested. The amounts ordered are compared to an up to the minute inventory which determines instantly what amounts are available. With this system an experienced data entry operator can enter around 600 orders per day. Thirteen to fifteen thousand orders are processed annually by the George O. White State Nursery.

After all of the daily information has been entered, it is processed in what we call a daily run. This is run after hours on an IBM AS/400 Mini-Computer. During this run, Acknowledgment (Billing) cards are issued along with an assortment of reports. Later in the season, shipping labels and tree cards are also issued.

The Acknowledgment (Billing) card is a two part card. The top portion contains a bar code, amount due, name and address and order number. The bottom portion contains all the species information for the customer. The top part of the card is returned to us with payment. (figure 2)

If orders are not paid within 30 days of the entry date, the order is canceled automatically and the stock is put back into inventory.

When payment is returned, the bar code is scanned and the payment screen for that order comes up on the terminal. The bar code is scanned by using a SYMBOL model laser scanner. If the payment matches the amount on the screen, the payment is applied with one key. If the payment does not match the amount due, the amount due is changed and payment applied with one key stroke. Usually the customer will note why his payment submitted is different than originally due and an order change will be made to reflect this also. The utilization of a bar codes eliminates errors in entering order numbers. The money we receive is deposited daily in the local bank. During the daily run, a listing of each applied payment is printed. This is used as a reference, and as an audit trail.

Seedlings are shipped from February until May. During a

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[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

[2] *Computer Operator, G. White State Nursery, Missouri Dept of Conservation, Licking, MO 65542*

daily run, tree cards (figure 3) and shipping tags (figure 4) are issued. They are issued if they meet certain conditions.

1. No money is due on the order.
2. The seedlings requested must be out of the field and graded.
3. The order is within the geographic zone scheduled for any given shipping date.

A maximum of 2000 bundles are allowed for any given shipping date. The shipping tag also utilizes a bar code. This bar code consists of a bundle number and the first three digits of the destination zip code. This is used for a computerized United Parcel Service manifest.

We do not issue shipping tags unless the seedlings ordered are out of the field and graded. Every day the grading supervisor enters the numbers and species graded that day. This gives us a beginning physical inventory, when shipping tags are issued, the computer subtracts that amount from the physical inventory. Unless this total shows a sufficient balance, no shipping tags are issued for that species. This should give us a total of what is actually in the cooler at any given time.

We do some type of order change to approximately 20 to 25% of our orders. A large number of these requests come via the telephone. Between November 1992 and May 1993, we received approximately 4200 phone calls at the nursery. In addition to that we have an 800 number for people to call and listen to a recording to receive information about what species are available and shipping information. More than 3800 people utilized that service, eliminating the manual handling of those phone calls.

Another feature that is unique to our system is the method of allocating previously sold out seedlings. We control the initiation of this process. If we see that we are going to have an overrun of seedlings, we select an option that searches through all orders that requested that species, but were not allocated them initially. The program creates billing cards for those orders. The card gives a due date and an amount due. No further transactions are done to the order until payment is received. (figure 5)

This system allows the initial processing plus all shipping and financial documentation of 13,000 to 15,000 seedling orders to be handled by one computer operator, one data entry operator and one temporary (1 to 2 months) clerical employee. The system was designed and written by Missouri Department of Conservation personnel.

ORDER FORM

DO NOT SEND MONEY WITH YOUR ORDER, YOU WILL BE BILLED THE CORRECT AMOUNT

CAT NO.	QTY	SPECIES	COST
422	25	Hazelnut	
211	25	White Pine	
413	25	Mulberry	
426	50	Aromatic Sumac	

Check here if you want us to substitute for sold out items --> ☐

ORDER TOTAL ____

4.725% Sales Tax
If this is a tax exempt order, attach tax exemption certificate ____

Handling Charge $3.00

TOTAL DUE ____

DATE: 7-13-93
NAME: Daniel Ray
ADDRESS: Rt 2 Box 128
CITY & STATE: Hillsboro, MO
PHONE: (____)________ ZIP 63050

If shipping address is different from above enter below (U.P.S. must have a street address).
NAME:
ADDRESS:
CITY & STATE:
PHONE: (____)________ ZIP____

DELIVERY OF ORDER
(Select one method only)

1. SHIP my order from the nursery during________ (Enter February, March, April or May)
2. I will PICK UP my order at the NURSERY during ________(Enter February, March, April or May)

My trees will be planted in__________COUNTY

OFFICE USE ONLY

Applc 94 Y/N

User__A___B___C___D___E___F___G___H

Type__I___J___K___L___M___N___O___P

Order Type 1____Normal 2____Free
3____Contract
4____Normal, Ship N/PD
5____Contract, Ship N/PD

MAIL Y/N

TAX
0____NML
1____EXT1
2____EXT2
3____EXT3
4____EXT4

COUPON NO.
____
____

ATTACH ANY COUPONS HERE

*Certain conservation planting may qualify for a discount on the cost of seedlings ordered. See your local Conservation Department representative for details.

Figure 1

DO NOT SEND MONEY WITH YOUR ORDER. YOU WILL BE BILLED THE CORRECT AMOUNT.

TREES
MO DEPARTMENT OF CONSERVATION
P O BOX 119
LICKING MO 65542

RAY DANIEL
RT 2 BOX 128
HILLSBORO MO
63050

Order No. 13201

Amount Due 22.64

Due Date 08/12/93

RETURN THIS CARD WITH CHECK

Refer to order number 13201 in all communications. 7/13/93
CARD 1 OF 1

I N I T I A L I N V O I C E
FOR SHIPMENT

Species	Qty Ordered	Qty Availble	Qty Not Availble	Total Price
WHITE PINE	25	25	0	2.75
HAZELNUT	25	25	0	4.00
AROMAT SUM	50	50	0	8.00
RED MULBER	25	25	0	4.00

Total Sales:	18.75
Sales Tax:	.89
Handling Charge:	3.00

Your payment due date is 08/12/93

RETURN THIS CARD FOR YOUR RECORDS Total Due: 22.64

Figure 2

TREES
P. O. BOX 119
LICKING, MO 65542

: FIRST-CLASS MAIL :
: U.S. POSTAGE :
: PAID :
: LICKING, MO. :
: PERMIT NO. 999 :

Order Number: 217

Dear Tree Planter:

Your seedling order is scheduled to be shipped from the GEORGE O. WHITE STATE NURSERY in approximately 10 days. If you have not received the plants in 15 working days, please contact the nursery promptly at 314-674-3229.

BYE LISA
3833 ROCKCREEK TERRACE
HIGH RIDGE MO 63049

Figure 3

STATE OF MISSOURI
DEPARTMENT OF AGRICULTURE
Plant Industries Division
Jefferson City
OFFICE OF THE STATE ENTOMOLOGIST

NURSERY INSPECTION CERTIFICATE
Number 348

This is to certify that, in accordance with the Missouri Plant Law, the nursery and premises belonging to George O. White State Forest Nursery, Licking, Missouri, have been duly inspected on an annual basis by an authorized inspector and were found to be apparently free of injurious insect pests and plant diseases. This certificate is subject to revocation and other penalties under the provisions of the laws relating thereto.

STATE ENTOMOLOGIST

NOTICE: Missouri plant law, section 263.070, paragraph 5, specifies that anyone selling or offering for sale or distributing nursery stock in any other manner must annually obtain nursery dealers registration inspection certificate. This does not include nursery stock purchased for your own use. For more information contact the office of the State Entomologist, P.O. Box 630, Jefferson City, MO 65102, telephone: 314/751-2462.

PLEASE NOTE

If you are unable to plant your seedlings as soon as you receive them, keep them stored in a cool, dark place and keep the roots moist. Avoid storage in warm, moist, dark places or in direct sunlight.

GEORGE O. WHITE STATE FORESTRY NURSERY
MISSOURI DEPARTMENT OF CONSERVATION
LICKING, MISSOURI 65542

FIGURE 4

QTY.	SPECIES
25	WHITE PINE (3-0)

000000-00810
PU
1995

STRUB LYNN E
HCR 9 BOX 30
BUCYRUS MO 65444

Figure 4

TREES
MO DEPARTMENT OF CONSERVATION
P O BOX 119
LICKING MO 65542

The seedlings listed below which were not available at the time your order was received, are now available. If you are now interested in obtaining these seedlings, please pay the amount indicated by the due date shown.

Specie	306
Order No.	13201
Amount Due	16.75

RAY DANIEL
RT 2 BOX 128
HILLSBORO MO
63050

Due Date 08/30/93

RETURN THIS CARD WITH PAYMENT

Refer to order number 13201 in all communications. 7/15/93

S E E D L I N G S N O W A V A I L A B L E

Species	Qty Available	Total Price
BUR OAK	100	16.00

Total Sales:	16.00
Sales Tax:	.75

Your due date is 08/30/93

RETAIN THIS CARD FOR YOUR RECORDS Total Due: 16.75

Figure 5

Announcement of the Steiner Group Black Locust Exclusive Release Using Tissue Culture Protocol Propagation

The U. S. Department of Agriculture, Soil Conservation Service, Forest Service, Agricultural Research Service and the West Virginia Department of Agriculture announced the release of the **Steiner Group** black locust (*Robinia pseudoacacia* L.) in 1987.

The **Steiner Group** is comprised of three cultivars, 'Appalachia', 'Allegheny', and 'Algonquin'. They were selected primarily for superior growth rate and dominant stem characteristics. Consideration was also given to the degree of susceptibility to injury from the locust stem borer (*Megacyllene robina*).

Propagation of the black locust clones was entirely from root cuttings during the evaluation period. While this is a reasonable and reliable technique, the cost, combined with the difficulty of producing enough root cuttings, made commercial production economically unattractive.

The development of micropropagation techniques for black locust has dramatically changed the propagation potential, insuring clonal purity.

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[1] *Poster presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

In 1990, the Soil Conservation Service cooperated with the Department of Forestry at Michigan State University and tested the **Steiner Group's** adaptability of micropropagation. Each of the three cultivars ('Appalachia', 'Allegheny', and 'Algonquin') had excellent response. Thus, a protocol for micropropagation of the **Steiner Group** was prepared. The protocol not only outlines the step-by-step procedure but also includes information helpful to those inexperienced in micropropagation.

The Soil Conservation Service is responsible for developing and testing plants and techniques for conservation use. It is also responsible for identifying and cooperating with nurseries to produce and make available released plant materials to the public.

By way of this article, the Soil Conservation Service is extending a solicitation to interested parties who have the capabilities and desire to produce the **Steiner Group** black locust using micropropagation.

Interested parties are encouraged to respond, in writing, to the following items:

- Do you have tissue culture production facilities?
- What are your production capabilities from the facility?
- Location of facility. Is it within the black locust adaptability range?
- Do you have a greenhouse facility?
- Marketing proposal (plan for production and distribution).
- Examples of other micropropagated plants.
- Previous tissue culture experience.
- Capital investment capability proposal.
- Years in business.

The evaluation of your response by the Soil Conservation Service is an effort by the Service to determine the best means of making available to the public the **Steiner Group**.

Responses and/or inquiries can be submitted to the Soil Conservation Service, Attn. David W. Burgdorf, Plant Materials Specialist, 1405 S. Harrison Rd., Room 101, East Lansing, Michigan 48823-5243. Telephone: 517-337-6701 ext. 1211.

MINUTES FROM 1993 BUSINESS MEETING

The business meeting of the Intermountain Conservation Nursery Association was called to order by Tom Landis at 12:30 PM on Thursday, August 5.

Financial Report

Clark Fleege reported that a checking account was established in Halsey, Nebraska and that funds were sufficient to cover expenses for setting-up the 1995 meeting.

Old Business

1. Minutes from the Previous Meeting. Tom reported that the minutes from the 1991 ICNA meeting in Park City, Utah are published in the Proceedings from that meeting. The minutes were approved by a voice vote.

There was no other old business, and so the floor was opened to new business.

New Business

1. Proposal to form a single western nursery association

Tom made the following report:

Currently, there are two informal nursery associations in the Western States. The Western Forest Nursery Council was one of the original groups of the Western Forestry and Conservation Association. Its members come mainly from the West Coast and the group meets in even-numbered years. The Intermountain Conservation Nursery Association members come from the Great Plains and Intermountain areas and meet separately in odd-numbered years, and jointly with the Western Forest Nursery Council in even-numbered years.

A single western nursery association would have the following benefits:

1. The current system of two organizations and the meeting schedule is very confusing, especially for the Proceedings where the name changes from year to year.
2. One western organization would consolidate our political clout and also mesh well with the Western Council of State Foresters, which is our primary political contact and source of financial support.

At the 1992 business meeting of the Western Forest Nursery Council at Fallen Leaf Lake, California, the group voted to explore the possibility of combining of the Western Forest Nursery Council and Intermountain Conservation Nursery Association into a single organization. The "Western Forest and Conservation Nursery Association" would consist of two groups: the West Coast Section, which meets on even-numbered years, and the Intermountain Section, which would meet on odd-numbered years. This is the same meeting schedule that currently exists for the two organizations.

Tom presented a proposed charter which was modified from the existing Intermountain Conservation Nursery Association charter. A copy follows the minutes.

The proposal to combine the two groups was discussed in detail. In general, the group thought that it was a good idea. Randy Moench reported that his State Forester, Jim Hubbard, was very supportive of the reorganization and that perhaps the group could become a subcommittee to the Western Council of State Foresters. A formal motion to formally combine the ICNA and WFNC was made by Jeff Wischer and seconded by Dick Thatcher. The motion carried unanimously by voice vote.

Subsequent discussion on how to proceed with the reorganization resulted in the following suggestions:

1. Some members thought that rather than wait until the 1994 meeting for a vote by the Western Forest Nursery Council, a letter containing a ballot should be send to WFNC members.
2. To be certain that the momentum would not be lost, Tom Landis was asked to send a letter to the Western Council of State Foresters informing them of the decision. It was also suggested that the WFNCA solicit a sponsor on the Council to represent their interests.

3. Tom Landis agreed to pursue the affiliation with the Western Forestry and Conservation Association and prepare a report for the 1994 meeting of the Western Forest Nursery Council in Moscow, Idaho.

2. *Location of future meetings:*

1994 – The Western Forest Nursery Council will meet on August 15-19 in Moscow, Idaho, where the host will be the Forest Research Nursery of the University of Idaho. This will be a joint meeting with the Forest Nursery Association of British Columbia.

1995 – The Intermountain Conservation Nursery Association meeting will be hosted held in Bessey Nebraska on the traditional second week of August. The technical sessions will be housed at a convention center in North Platte, Nebraska and the meeting will include a field trip to the USDA Forest Service Bessey Nursery in Halsey, Nebraska. Nursery manager Clark Fleege and his staff will be our hosts.

1996 – Tom suggested a meeting in the Portland, Oregon area so that the Association would have the benefit of attending the Far West Show of the Oregon Association of Nurserymen. They typically meet at the Convention Center during the last week in August. Due to the expected impact of that group, the Association may need to consider meeting across the river in Vancouver, Washington. Several local nurseries could host the meeting including the USDA Forest Service Wind River Nursery in Carson, Washington.

1997 – The ICNA meeting is scheduled to be held in Wichita, Kansas and hosted by Jeff Wischer and the El Dorado Nursery of Kansas State and Extension Forestry.

There was no more new business and so the meeting was officially closed at 1:25 PM.

PROPOSED CHARTER FOR THE WESTERN FORESTRY AND CONSERVATION NURSERY ASSOCIATION

1. Mission Statement

The Western Forest and Conservation Nursery Association (WFCNA) is an organization of public and private nurseries from the Western United States whose focus is the production of seedlings (conifers, hardwoods, and shrubs) for forestry and conservation plantings. Members include producers of bareroot and container seedlings as well as seedling users, researchers, and technical support personnel. The Association provides a mechanism to share information, technologies; identify common needs among nurseries, researchers, and customers; and manage our resources for future generations.

2. Goals

- Share state-of-the-art nursery practices.
- Coordinate and facilitate applied nursery research.
- Facilitate communication and resource sharing among nurseries.
- Promote improved communication between nurseries and customers.
- Serve as advocate of forest and conservation nursery managers in professional and political forums.
- Encourage greater emphasis on woody plant production and use in forestry and conservation plantings: reforestation, biodiversity, wildlife habitat improvement, soil conservation, restoration, water quality, livestock protection, field and farmstead windbreaks, and living snow fences.

3. Membership

The WFCNA is open to all nursery personnel who are interested in the propagation of plants for forestry and conservation purposes. The organization is specifically defined by this function, rather than by any geographical boundaries. Nursery personnel who attend the association meeting and pay the registration fee have voting privileges at the business meeting.

4. Organization and Operations

To provide direction and continuity, the WFCNA will be represented by a Board of Directors that is made up of nursery personnel. The Board of Directors consists of two positions (chair, vice-chair), who serve two-year terms. The chair will be the host of the next meeting and the vice-chair will be the host of the succeeding meeting. The vice-chair becomes the chair at the business meeting, and a new vice-chair is determined by the location of the next meeting. Ex-officio members include the Western Nursery Specialist, and the Director of the Center of Semiarid Agroforestry at the Rocky Mountain Forest and Range Experiment Station at Lincoln.

All official business of the WFCNA will take place at the annual meeting, which will be held at a member nursery. The location of the meetings will be established on a rotating basis, and announced two years in advance. The meeting will be held on a Tuesday, Wednesday, and Thursday in early August, and consist of two days of presentations and workshops, combined with field trips to nurseries and outplanting sites. The Board of Directors will meet on the Monday afternoon preceding the meeting to formulate resolutions to put before the general membership at the Wednesday business meeting. They will meet again on the following Friday morning to act on the resolutions.

The goals of the WFCNA will be promoted by two separate, but related programs: applied research and technology transfer projects. Applied Research refers to projects in which existing techniques from horticulture or other related fields will be modified and adapted to the conditions at member nurseries. No attempt

will be made to do basic research where new information is created. Technology Transfer projects will involve organizing workshops and training sessions to inform members of existing technical information.

5. Applied Research Projects

One of the key aspects of the WFCNA is to promote applied research projects among member nurseries that will increase seedling quality and outplanting success. Selection criteria for these projects will include:

- Widespread application to member nurseries
- High probability of success
- Immediate usefulness
- Must translate into outplanting success

The exact mechanism for initiating these applied research projects still needs to be developed, especially ways to procure funding. The possibility of establishing a Research Coordinator will be investigated. The Coordinator would be appointed by the Board of Directors and would be responsible for surveying member nurseries to identify research needs, and report these needs to the Board. Acting upon the recommendations of the Board, the Research Coordinator would implement the research programs at participating member nurseries. The Research Coordinator would also provide problem solving services and site-specific research to member nurseries on a fee basis.

6. Technology Transfer Projects

Technology transfer needs and priorities will be determined by common consensus of the member nurseries. Because it is difficult for members to obtain approval to travel to separate training sessions, special "focus topics" will be scheduled at the regular nursery meetings. The Western Nursery Specialist and the Director of the Semiarid Agroforestry Center will assist in planning and implementing these projects.

7. Political and Fiscal Support

The WFCNA will not exist as a separate entity, but will operate as a subcommittee of the Western Forestry and Conservation Organization, which is headquartered in Portland, Oregon. In addition, a political liaison with the Western Association of State Foresters is desirable. The WFCNA will attempt to secure representation through a State Forester who would serve as an advocate. The WFCNA also maintains a technical liaison with the Center for Semiarid Agroforestry in Lincoln, Nebraska, and the Western Nursery Specialist of the USDA Forest Service will also serve as technical advisor and political advocate.

Annual meeting costs will be covered by meeting registration fees and by fees paid by commercial exhibitors. A checking account will be established under the auspices of the Western Forestry and Conservation Association which will insure proper accounting and tax-free status. The vice-chair will serve as treasurer of this account and make a financial report at the annual meeting. Carryover funds from the previous year's meeting will function as a reserve fund to cover mailings, room deposits, and other expenses associated with setting up the next meeting. If the account exceeds $2,500, the money will be used to defray registration costs of the next meeting.

List of Attendees

Northeastern and Intermountain Forest and Conservation Nursery Associations
August 2-5, 1994; St Louis Missouri

Exhibitors

Baertschi of America, Inc.
Fobro
Paul Bennett
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Sevierville, Tn. 37864

Stuewe and Sons, Inc.
Eric Stuewe
2290 S.E. Kiger Island Rd.
Corvallis, Or. 97331

Louisiana Forest Seed Co.
Gary and John Delaney
303 Forestry Rd.
Lecompte, La. 71346

Union Camp Corporation
Pat Pinckney
801 Summer Lane
Prattville, Al. 36067

Holland Transplanter
Hugh Gerhardt
510 E. 16th
Holland, Mi. 49423

Tree Pro
445 Lourdes Lane
Lafayette, In. 47905

Truax Company, Inc.
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Tree Sentry
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Northeastern and Intermountain
Nurserymen's Conference
St. Louis, August 1-5, 1993

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1994-574-960/05055

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526